APPENDIX D

STATISTICAL ANALYSIS

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MEMORANDUM

From: Jim Markwiese, Paul Black, Tom Stockton, Doug Bronson, Andrew Schuh

To: Scott Jacobs, Ann Vega

Date: 24 September 2003

Subject: Statistical Analysis for Bioreactor Study

Some preliminary data analyses, replicate analyses, and trend analyses are presented in the attached document for the data collected from the bioreactor experiments for WMI. Data have been provided by WMI for leachate for the 3 units, FLB, AALB, and control, and for solids, field gas, and landfill gas for the 2 units, FLB, and control (see attachment on data sources). The data are limited, reflecting the early stages of data collection for this 5-year project. The statistical analyses follow. Interpretation of the plots should consider the following notes:

1. The time plots presented below have different y-axis scales, so some care should be taken during interpretation. The x-axis scales are the same for each set of plots.

2. Lines drawn on the time plots are smoothed regression lines (using the LOESS function) when there are sufficient data (including detections).

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This plots give the reader some sense of the date of activity of the landfills as well as the dates for which data is available for them.

III. SUMMARY STATISTICS FOR LEACHATE AND GAS DATA

These are the basic statistics for the field gas and leachate including mean, median, quantiles, min, max, and standard deviation for data subset out by cell and replicate (A/B).

IV. LEACHATE TIME PLOTS

This is a good place to start for the leachate data as it gives the reader a good overall feeling for the behavior of the data. Rigorous statistical analysis of trends and replicates is left to sections VI. and IX.

V. LEACHATE REPLICATE ANALYSIS

This section investigates the differences between the replicates of each of the cells (FLB cell 5.1, FLB cell 5.2, Control cell 7.3, and 7.4). Also included is an analysis of some alternative replicate configurations based upon "after the fact" knowledge of the geometry and location of the cells and their replicates. Essentially, different polynomial models are fit to the data, a best model form chosen, and then the parameters are tested for significant differences.

VI. FIELD GAS TIME PLOTS

This section includes time plots of the field gas data and is a good place to start when trying to understand this data.

VII. FIELD GAS BOX PLOTS

This section contains boxplots of the field gas data with the Date variable being "collapsed". Essentially these are additional diagnostic plots that provides a visual picture of overall concentrations.

VIII. TREND TESTS

This section tracks our attempts to detect statistically significant trends in the leachate data. It also includes some slope estimates which may be useful when a significant trend is evident.

IX. LEVELPLOT OF SETTLING HEIGHT CHANGE

This is a simple "contour" style LOESS plot of the settling height change. No rigorous statistical tests are performed on this data and this plot is included for qualitative purposes only.

X. DATA SUMMARY

This is a summary of the data we have received up until this point in time.

Summary

At this point in the CRADA there is a major difficulty in comparing the treatment cells (FLB and AALB) to the control cells due to several confounding factors. As time progresses and more data become available, some of these confounding factors (e.g., non-overlapping aged waste between cells) are expected to become less of a hindrance to statistical analysis. For now, however, if a difference is found between types of cells, it is challenging to determine if the difference is due to treatment or age. Confounding factors that could have an effect on critical parameters are:

- geometry of cell
- amount of waste disposed in cell
- type of waste disposed in cell
- time of waste disposal in cell

As further data are collected, these factors can be addressed.

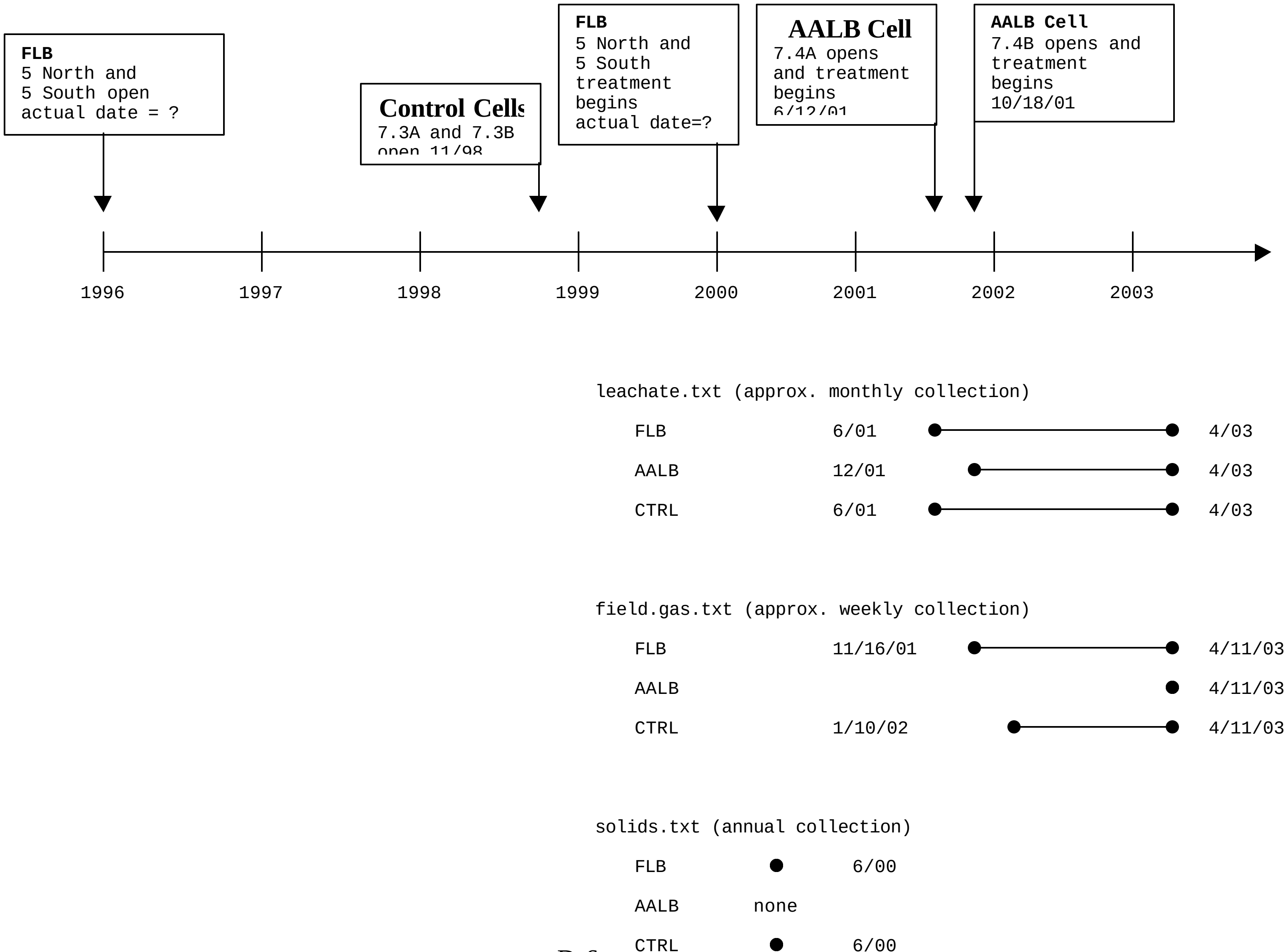
Because of the difficulties above, the main focus of this document will be on: exploratory data analysis of critical leachate and field gas parameter along with the comparison of the A and B pairs of cells. The comparison is important because the pairs are intended to be replicates, but have been subjected to different conditions. Other topics include trend analysis of critical parameters and initial exploratory data analysis of the solids and settling data.

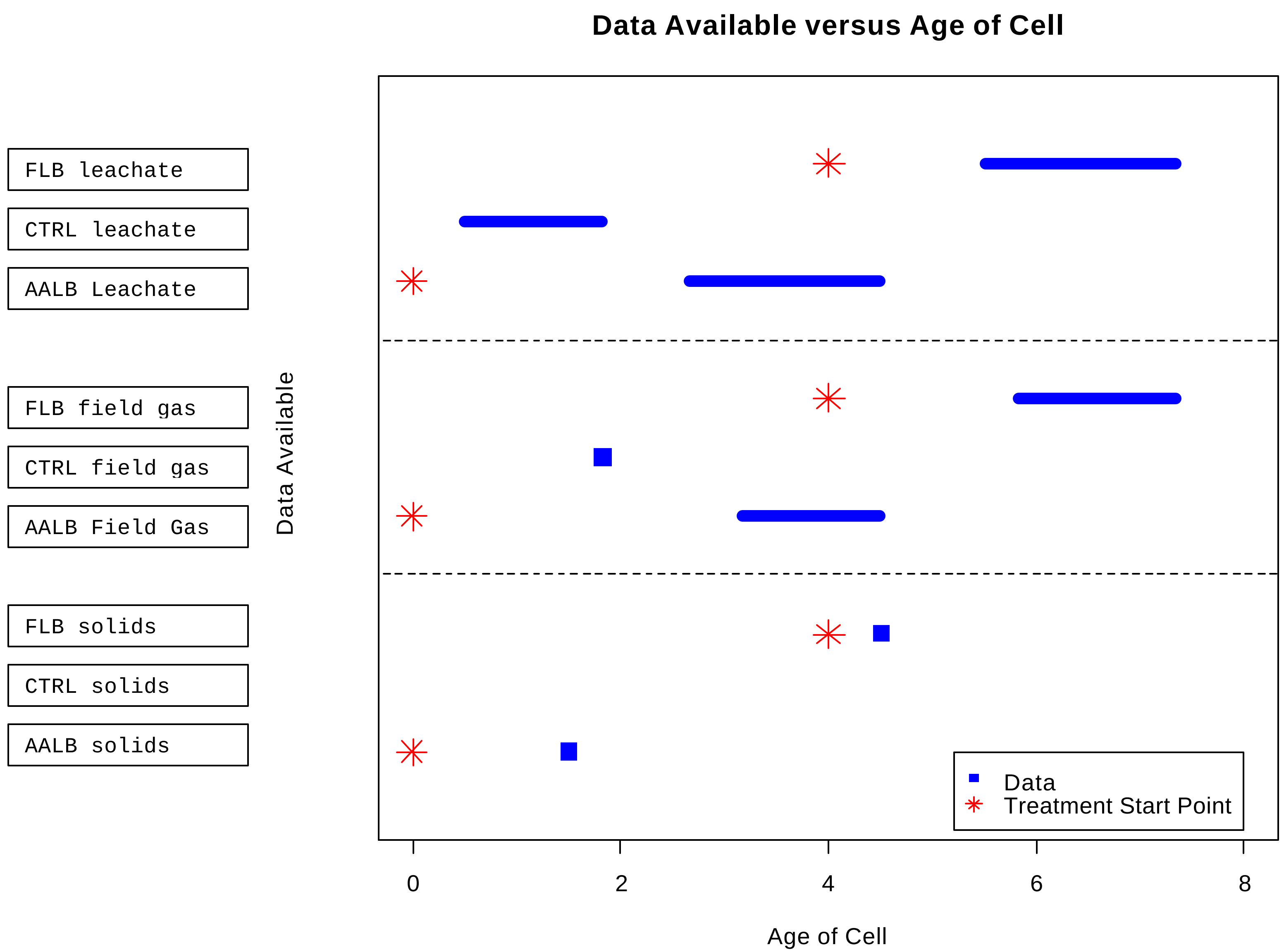
Leachate data has been collected quarterly, so sample sizes are approximately 20 within each cell. Also, data values are highly variable and there are many confounding variables. These factors make modeling or comparing cells very difficult. Still, visual inspection of LOESS smooths of the time plots and analysis of covariance F-tests demonstrate that the A and B pairs within cells are similar.

Field Gas data has been collected weekly and values are far less variable than the leachate data. Time plots indicate that concentrations in control and FLB cell 5.1 are quite similar. Concentrations are flat and linear. On the contrary, concentrations in FLB cell 5.2 follow a definite non-linear trend. Time plots and box-plots indicate concentrations in FLB cells are higher in variability than in the control cells.

BIOREACTOR CELL TIMELINES

CELL AGE AND DATA TIMELINE




Data Available versus Age of Cell
FLB leachate
CTRL leachate
AALB Leachate
FLB field gas
CTRL field gas
AALB Field Gas
FLB solids
CTRL solids
AALB solids
Data Available
Data
Treatment Start Point
0
2
4
6
8
Age of Cell

SUMMARY STATISTICS
FOR LEACHATE AND GAS FIELD DATA
(data thru Spring 2003)

LEACHATE

	cell	id	n	min	Q1	median	mean	Q3	max	sd
Acetic Acid	FLB 5.1	A	18	1.0	1.6	3.3	163.0	5.0	2350	552.31
	FLB 5.1	B	18	1.0	2.1	3.4	10.9	7.0	80	19.24
	FLB 5.2	A	18	1.0	2.5	3.8	5.6	8.0	20	4.89
	FLB 5.2	B	18	1.0	1.6	2.3	150.1	22.3	2340	548.46
	Control 7.3	A	18	1.0	1.0	1.9	24.1	2.5	389	91.14
	Control 7.3	B	17	1.0	1.9	11.0	109.3	44.0	1010	263.81
	AALB 7.4	A	17	1.0	10.0	243.0	484.2	1010.0	1650	554.73
	AALB 7.4	B	17	2.9	23.0	151.0	582.1	539.0	2580	845.87

	cell	id	n	min	Q1	median	mean	Q3	max	sd
Ammonia (As N, MG/L)	FLB 5.1	A	21	551	831.0	1070.0	2444.5	1590.0	19200	4410.3
	FLB 5.1	B	21	468	707.0	976.0	1168.8	1410.0	3100	678.7
	FLB 5.2	A	20	291	865.0	1325.0	1278.1	1570.0	2580	551.6
	FLB 5.2	B	21	432	723.0	877.0	1290.5	1250.0	7010	1392.5
	Control 7.3	A	20	67.1	108.5	298.0	459.8	585.8	1420	432.3
	Control 7.3	B	19	48.6	114.5	239.0	376.1	409.5	1410	406.1
	AALB 7.4	A	17	162	545.0	741.0	922.1	942.0	2720	653.4
	AALB 7.4	B	17	97.3	650.0	1040.0	920.7	1320.0	1540	462.8

	cell	id	n	min	Q1	median	mean	Q3	max	sd
BOD (MG/L)	FLB 5.1	A	22	32.9	61.8	95.5	189.0	216.8	1060	228.7
	FLB 5.1	B	23	21.7	74.3	119.0	165.4	228.0	629	145.2
	FLB 5.2	A	20	19.8	52.2	127.0	138.0	181.3	414	100.1
	FLB 5.2	B	21	24.9	58.7	84.5	156.0	159.0	783	185.7
	Control 7.3	A	20	14.6	34.0	49.9	155.6	99.0	1820	395.4
	Control 7.3	B	21	9.2	45.5	158.0	1784.0	198.0	31400	6805.0
	AALB 7.4	A	20	20.0	182.3	469.0	1967.0	2378.0	15000	3427.1
	AALB 7.4	B	18	142.0	517.8	2085.0	6233.0	6280.0	54400	12546.6

	cell	id	n	min	Q1	median	mean	Q3	max	sd
Chloride (MG/L)	FLB 5.1	A	9	818	1460.0	1850.0	1694.2	2060.0	2250	467.2
	FLB 5.1	B	8	955	1570.0	2485.0	2154.4	2732.5	2840	736.0
	FLB 5.2	A	7	1110	1355.0	1920.0	2027.1	2700.0	3050	794.4
	FLB 5.2	B	9	10	860.0	1180.0	1072.1	1390.0	1930	547.2
	FLB 5.1	A	9	818	1460.0	1850.0	1694.2	2060.0	2250	467.2
	FLB 5.1	B	8	955	1570.0	2485.0	2154.4	2732.5	2840	736.0
	FLB 5.2	A	7	1110	1355.0	1920.0	2027.1	2700.0	3050	794.4
	FLB 5.2	B	9	10	860.0	1180.0	1072.1	1390.0	1930	547.2

	cell	id	n	min	Q1	median	mean	Q3	max	sd
COD (MG/L)	FLB 5.1	A	21	882.0	1790	1890	1848.0	1970.0	2620	449.1
	FLB 5.1	B	21	1000.0	1250	1560	1659.0	1960.0	2530	486.8
	FLB 5.2	A	20	10.0	1035	1595	1638.0	2140.0	3840	1054.1
	FLB 5.2	B	21	114.0	1200	1350	1366.0	1440.0	3560	640.7
	Control 7.3	A	20	114.0	259	435	667.2	687.3	3170	721.0
	Control 7.3	B	19	60.3	235	618	963.8	992.0	5720	1297.2
	AALB 7.4	A	17	916.0	1580	2290	5282.0	6030.0	30900	7488.5
	AALB 7.4	B	17	1840.0	2250	4220	7222.0	9330.0	26000	7039. 3

	cell	id	n	min	Q1	median	mean	Q3	max	sd
Nitrite (As N, MG/L)	FLB 5.1	A	21	0.02	0.03	0.06	0.08	0.10	0.28	0.07
	FLB 5.1	B	20	0.02	0.02	0.07	0.12	0.12	0.71	0.17
	FLB 5.2	A	19	0.02	0.02	0.07	0.08	0.11	0.38	0.09
	FLB 5.2	B	21	0.02	0.02	0.03	0.06	0.08	0.24	0.06
	Control 7.3	A	20	0.02	0.02	0.02	0.06	0.09	0.28	0.07
	Control 7.3	B	19	0.02	0.02	0.06	0.19	0.10	2.00	0.45
	AALB 7.4	A	17	0.05	0.12	0.19	0.24	0.32	0.65	0.18
	AALB 7.4	B	17	0.09	0.12	0.17	1.30	0.44	10.70	2.78

	cell	id	n	min	Q1	median	mean	Q3	max	sd
Nitrogen (Nitrate, MG/L)	FLB 5.1	A	21	0.02	0.02	0.04	0.06	0.10	0.13	0.04
	FLB 5.1	B	20	0.02	0.02	0.02	0.09	0.10	0.57	0.13
	FLB 5.2	A	19	0.02	0.02	0.02	0.07	0.09	0.28	0.07
	FLB 5.2	B	21	0.02	0.02	0.02	0.04	0.05	0.20	0.05
	Control 7.3	A	20	0.02	0.02	0.02	0.05	0.03	0.20	0.06
	Control 7.3	B	19	0.02	0.02	0.03	0.05	0.05	0.26	0.06
	AALB 7.4	A	17	0.02	0.02	0.10	0.22	0.19	1.70	0.40
	AALB 7.4	B	17	0.02	0.10	0.18	2.31	1.00	26.50	6.38

	cell	id	n	min	Q1	median	mean	Q3	max	sd
PH (S.U.)	FLB 5.1	A	21	6.92	7.14	7.22	7.222	7.34	7.56	0.15513
	FLB 5.1	B	21	6.95	7.17	7.30	7.255	7.36	7.51	0.16046
	FLB 5.2	A	20	6.65	7.15	7.28	7.244	7.36	7.62	0.20671
	FLB 5.2	B	21	6.84	7.10	7.16	7.161	7.28	7.33	0.13203
	Control 7.3	A	20	6.38	6.55	6.88	6.834	7.05	7.31	0.29601
	Control 7.3	B	19	6.14	6.42	6.85	6.752	7.05	7.20	0.33671
	AALB 7.4	A	17	6.31	7.01	7.13	7.072	7.20	7.40	0.27369
	AALB 7.4	B	17	5.89	6.64	7.11	6.964	7.37	7.57	0.50964

Phosphate, Ortho (MG P/L)	cell	id	n	min	Q1	median	mean	Q3	max	sd
	FLB 5.1	A	21	1.6	2.5	2.7	2.9	3.4	4.6	0.8
	FLB 5.1	B	20	0.98	1.6	2.3	2.6	3.2	6.4	1.3
	FLB 5.2	A	19	1.4	2.9	3.4	4.0	4.7	7.8	1.9
	FLB 5.2	B	21	0.54	1.2	1.9	2.0	2.3	6.8	1.3
	Control 7.3	A	20	0.08	0.7	0.9	1.1	1.4	3.4	0.8
	Control 7.3	B	19	0.27	0.6	0.8	1.1	1.2	4.8	1.0
	AALB 7.4	A	17	0.8	1.7	1.9	3.4	3.6	15.4	3.5
	AALB 7.4	B	17	1.2	2.1	3.4	3.7	4.7	8.2	2.0

Phosphorous, Total (MG P/L)	cell	id	n	min	Q1	median	mean	Q3	max	sd
	FLB 5.1	A	21	0.77	2.4	2.7	2.9	3.5	5.3	1.2
	FLB 5.1	B	21	0.12	1.6	2.0	3.0	2.9	17.8	3.7
	FLB 5.2	A	20	1.3	3.1	4.4	4.7	6.8	9.9	2.4
	FLB 5.2	B	21	1	1.5	2.3	3.2	3.2	14.2	2.9
	Control 7.3	A	20	0.11	0.7	0.9	1.5	1.9	5.3	1.3
	Control 7.3	B	19	0.11	0.8	1.4	1.8	2.3	5.6	1.5
	AALB 7.4	A	17	0.92	2.8	3.5	5.4	8.3	21.6	5.1
	AALB 7.4	B	17	0.33	1.7	3.1	3.8	4.2	10.5	3.2

Temperature (°C)	cell	id	n	min	Q1	median	mean	Q3	max	sd
	FLB 5.1	A	21	23.0	26.8	30.5	29.58	31.4	34.6	3.4048
	FLB 5.1	B	21	23.5	26.1	27.0	27.91	29.7	32.9	2.6107
	FLB 5.2	A	20	19.0	27.9	30.3	29.28	31.9	35.3	4.6443
	FLB 5.2	B	20	21.1	24.5	25.7	25.82	27.0	31.1	2.5980
	Control 7.3	A	20	9.5	11.9	15.1	16.24	19.1	25.3	4.9550
	Control 7.3	B	19	6.8	12.3	18.2	16.99	20.1	25.1	5.2618
	AALB 7.4	A	17	19.8	24.8	30.6	29.08	33.0	34.7	4.6699
	AALB 7.4	B	17	15.3	21.9	26.3	24.96	28.6	33.8	5.4191

Total Kjeldahl Nitrogen (TKN)	cell	id	n	min	Q1	median	mean	Q3	max	sd
	FLB 5.1	A	9	189	612.0	955.0	812.7	1040.0	1160	348.8
	FLB 5.1	B	9	362	526.0	1030.0	882.8	1200.0	1250	370.6
	FLB 5.2	A	8	445	643.3	1088.0	1032.0	1355.0	1580	432.2
	FLB 5.2	B	9	89.2	394.0	505.0	585.2	1010.0	1040	365.6
	Control 7.3	A	8	91.9	123.8	179.0	194.1	236.8	371	94.1
	Control 7.3	B	8	12.6	36.5	55.3	94.7	83.0	390	123.1
	AALB 7.4	A	5	26.5	118.0	260.0	246.7	395.0	434	174.9
	AALB 7.4	B	5	100	169.0	171.0	298.6	332.0	721	251.0

FIELD GAS

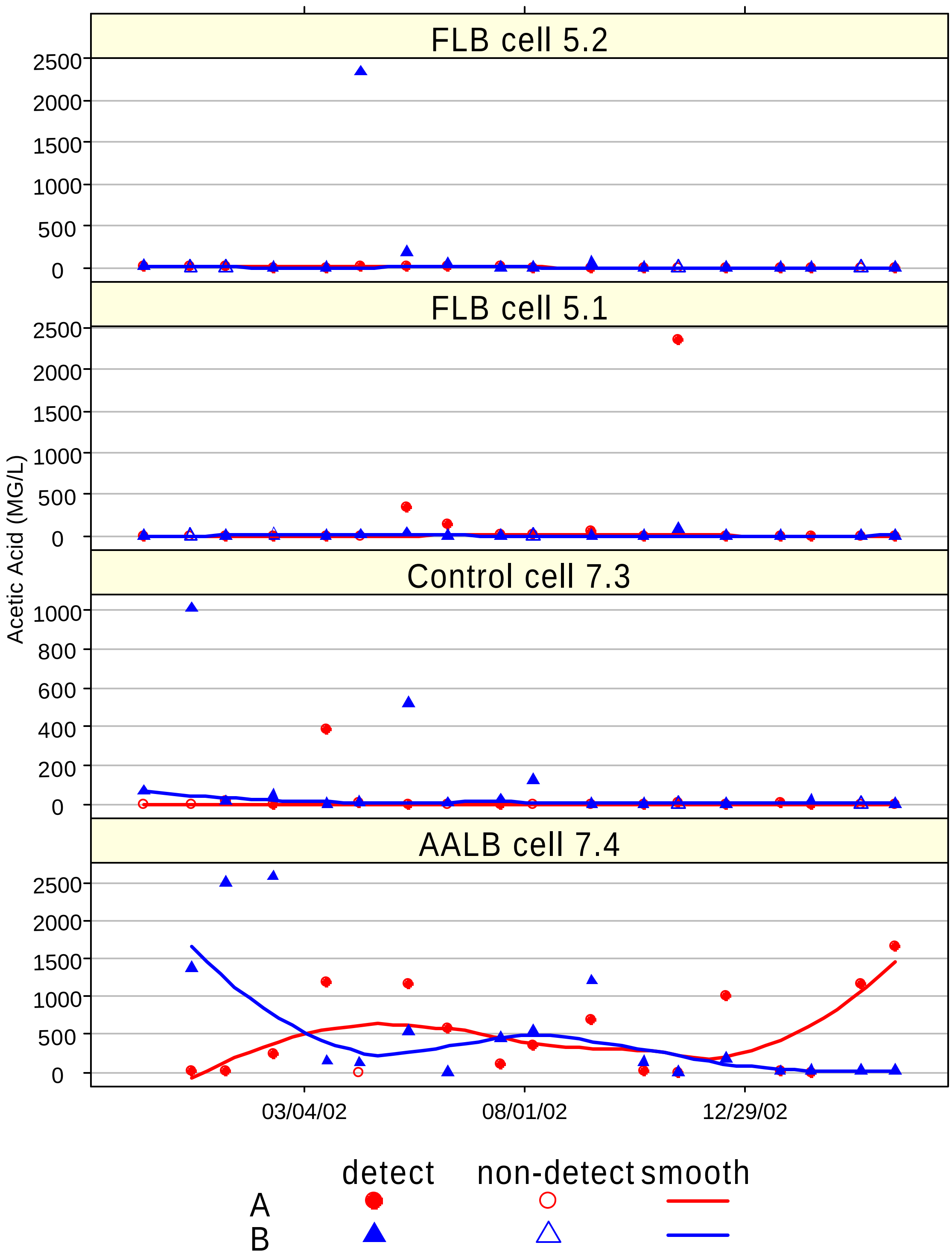
	cell	id	n	min	Q1	median	mean	Q3	max	sd
CH4	FLB 5.1		207	3.9	47.0	52.2	49.43	55.3	99.9	11.2770
	FLB 5.2		208	3.9	26.3	39. 5	38.04	53.9	61.9	16.6666
	Control 7.3	A	334	44.4	56.7	57.4	58.32	58.6	69.1	3.3828
	Control 7.3	B	353	51.0	56.4	57.6	57.27	58.4	62.7	1.9394
	AALB 7.4	A	4	54.5	54.5	54.7	54.65	54.8	54.8	0.1732
	AALB 7.4	B	3	54.7	54.8	54.8	54.80	54.9	54.9	0.1000

	cell	id	n	min	Q1	median	mean	Q3	max	sd
CO2	FLB 5.1		207	3.2	33.0	36.8	34.79	38.7	45.7	7.3830
	FLB 5.2		208	3.1	19.9	29. 5	28.16	39.4	46.8	11.9248
	Control 7.3	A	334	29.2	41.7	42.5	42.19	43.1	45.2	1.6187
	Control 7.3	B	353	36.6	40.2	41.3	41.11	42.0	44.7	1.2481
	AALB 7.4	A	4	41.7	41.7	41.7	41.73	41.7	41.8	0.0500
	AALB 7.4	B	3	42.2	42.2	42.2	42.23	42.3	42.3	0.0577

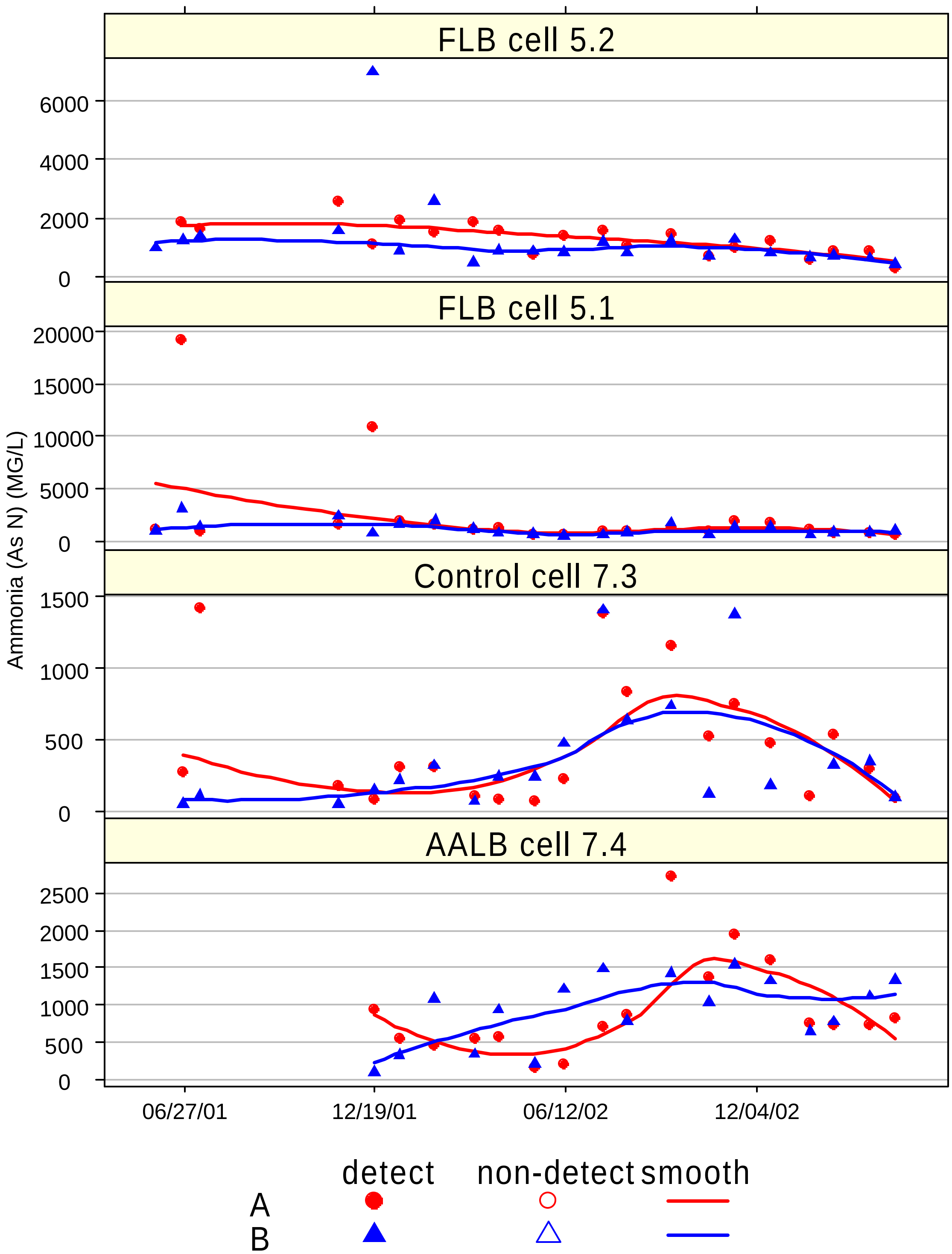
	cell	id	n	min	Q1	median	mean	Q3	max	sd
O2	FLB 5.1		207	0.1	1.3	2.1	3.436	4.3	18.7	3.5951
	FLB 5.2		208	0.0	1.3	6.6	6.641	10.0	18.9	5.4264
	Control 7.3	A	334	0.0	0.0	0.0	0.273	0.2	12.9	0.9682
	Control 7.3	B	353	0.0	0.0	0.0	0.331	0.4	8.4	0.7174
	AALB 7.4	A	4	0.7	0.7	0.9	0.850	1.0	1.0	0.1732
	AALB 7.4	B	3	0.8	0.9	0.9	0.867	0.9	0.9	0.0577

LEACHATE TIME PLOTS

Acetic Acid

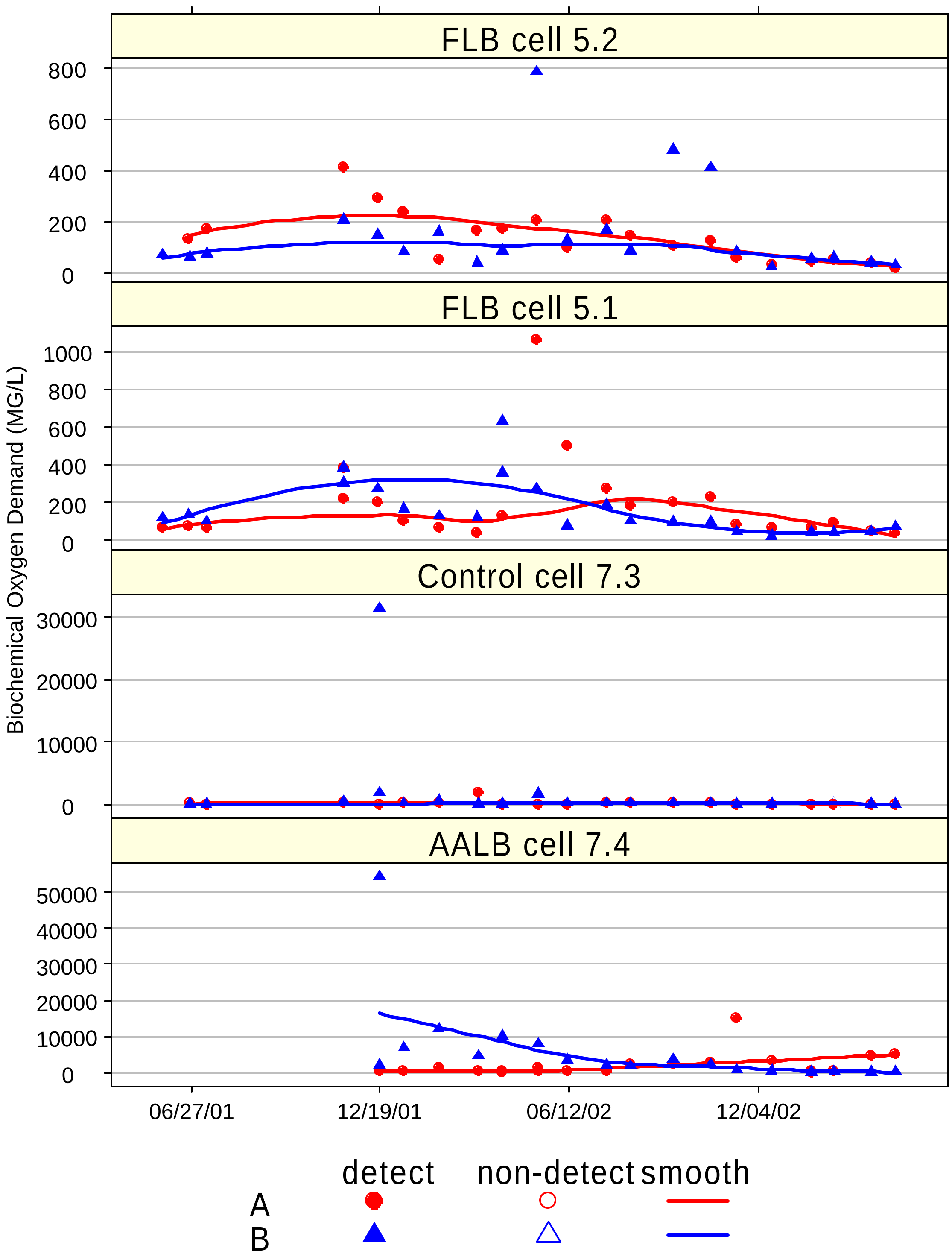

FLB cell 5.2
FLB cell 5.1
Control cell 7.3
AALB cell 7.4
2500
2000
1500
1000
500
0
800
600
400
200
Acetic Acid (MG/L)
03/04/02
08/01/02
12/29/02
detect
non-detect
smooth
A
B

Ammonia (as N)

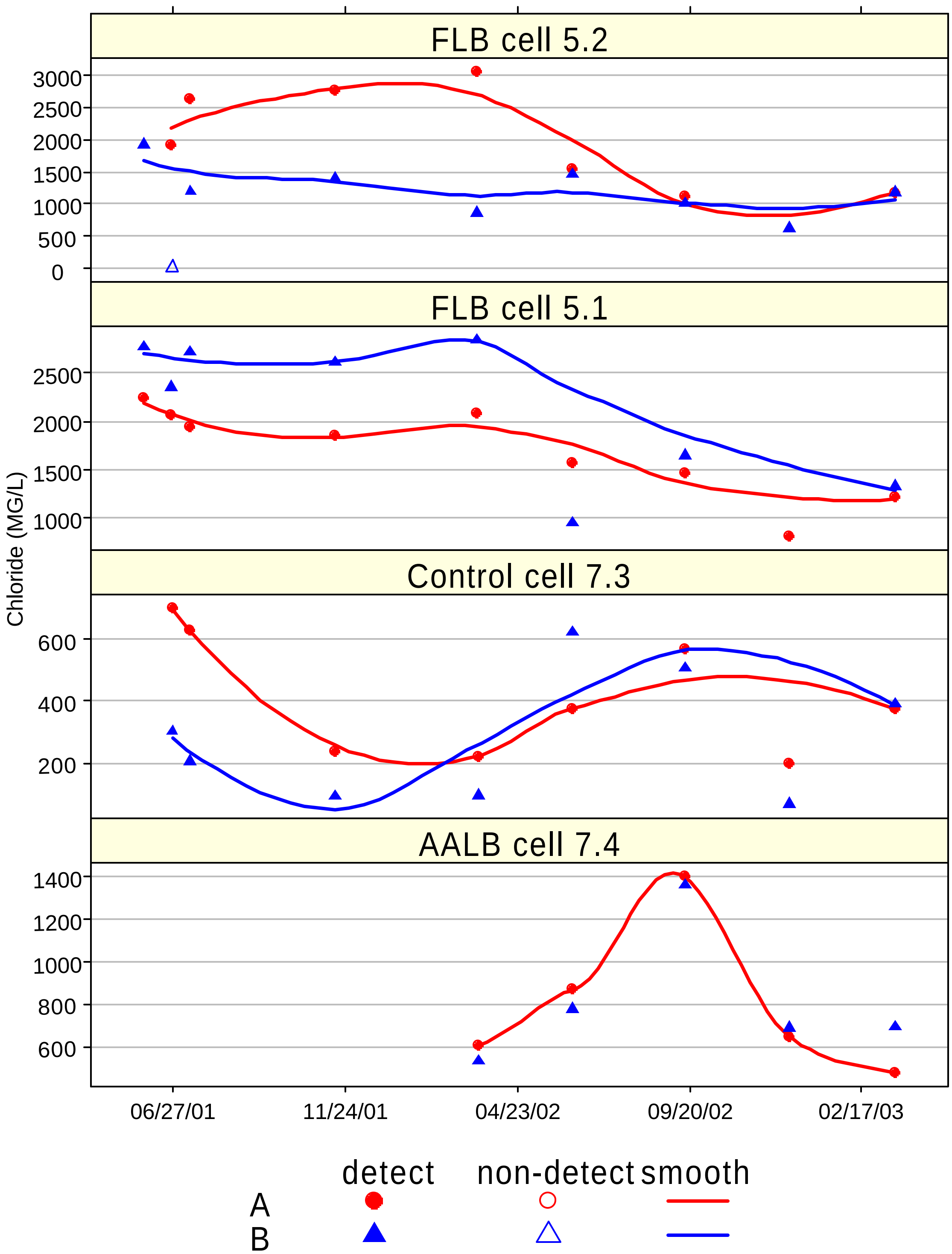


FLB cell 5.2
6000
4000
2000
0
FLB cell 5.1
20000
15000
10000
5000
0
Control cell 7.3
1500
1000
500
0
AALB cell 7.4
2500
2000
1500
1000
500
0
Ammonia (As N) (MG/L)
06/27/01
12/19/01
06/12/02
12/04/02
detect
non-detect
smooth
A
B

Biochemical Oxygen Demand (BOD)

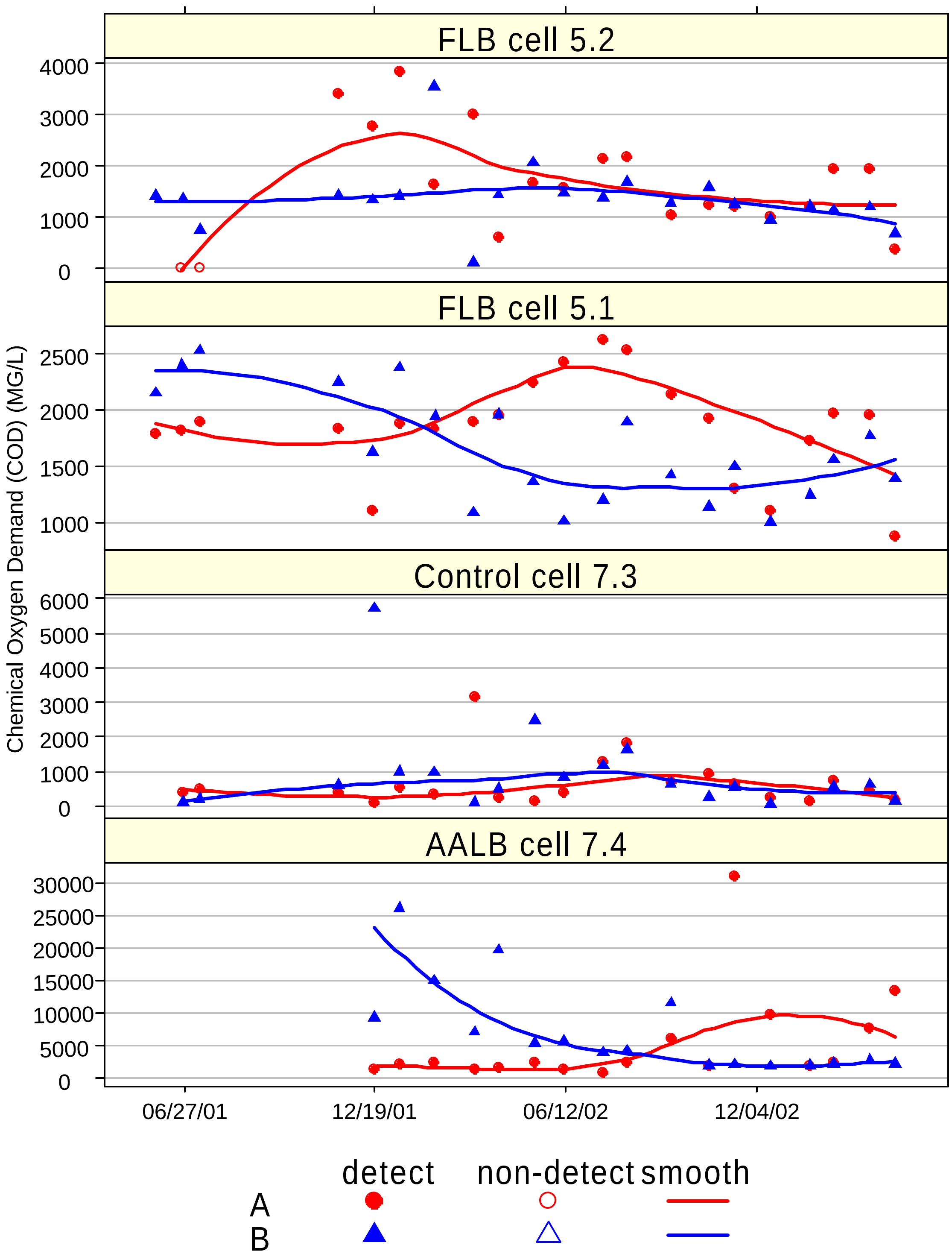


Chloride

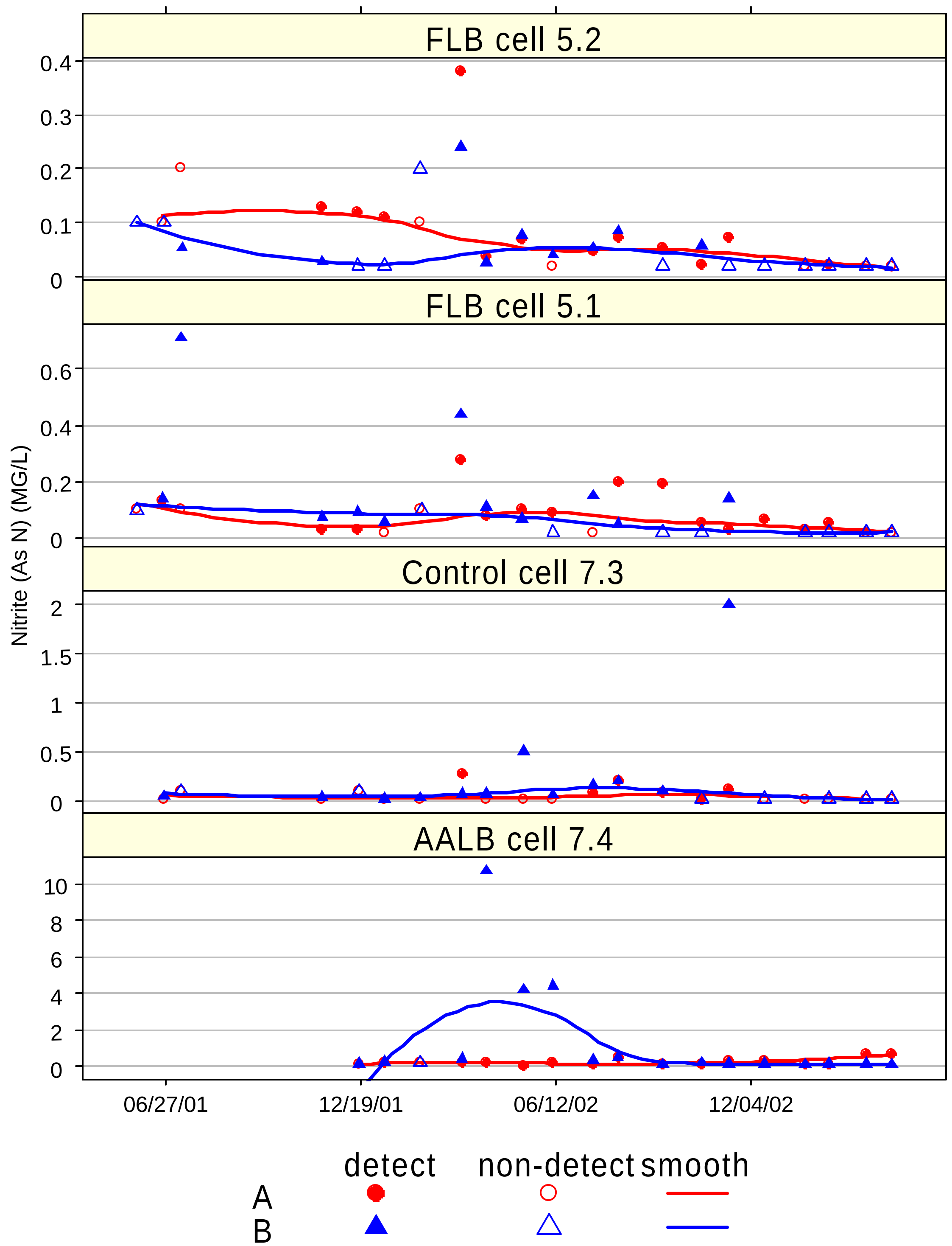


FLB cell 5.2
FLB cell 5.1
Control cell 7.3
AALB cell 7.4
Chloride (MG/L)
3000
2500
2000
1500
1000
500
0
600
400
200
1400
1200
800
06/27/01
11/24/01
04/23/02
09/20/02
02/17/03
detect
non-detect
smooth
A
B

Chemical Oxygen Demand (COD)

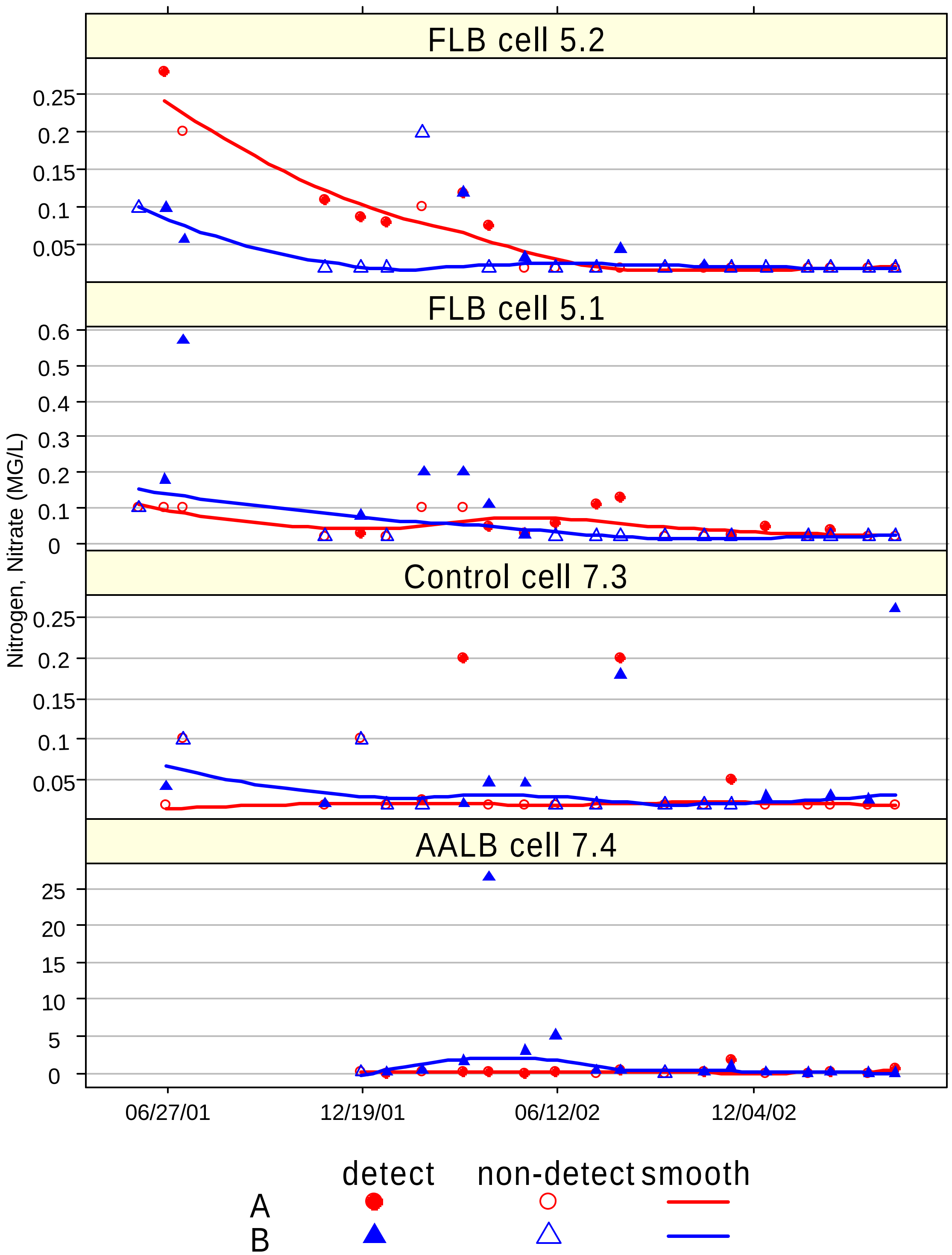


Nitrate (as N)

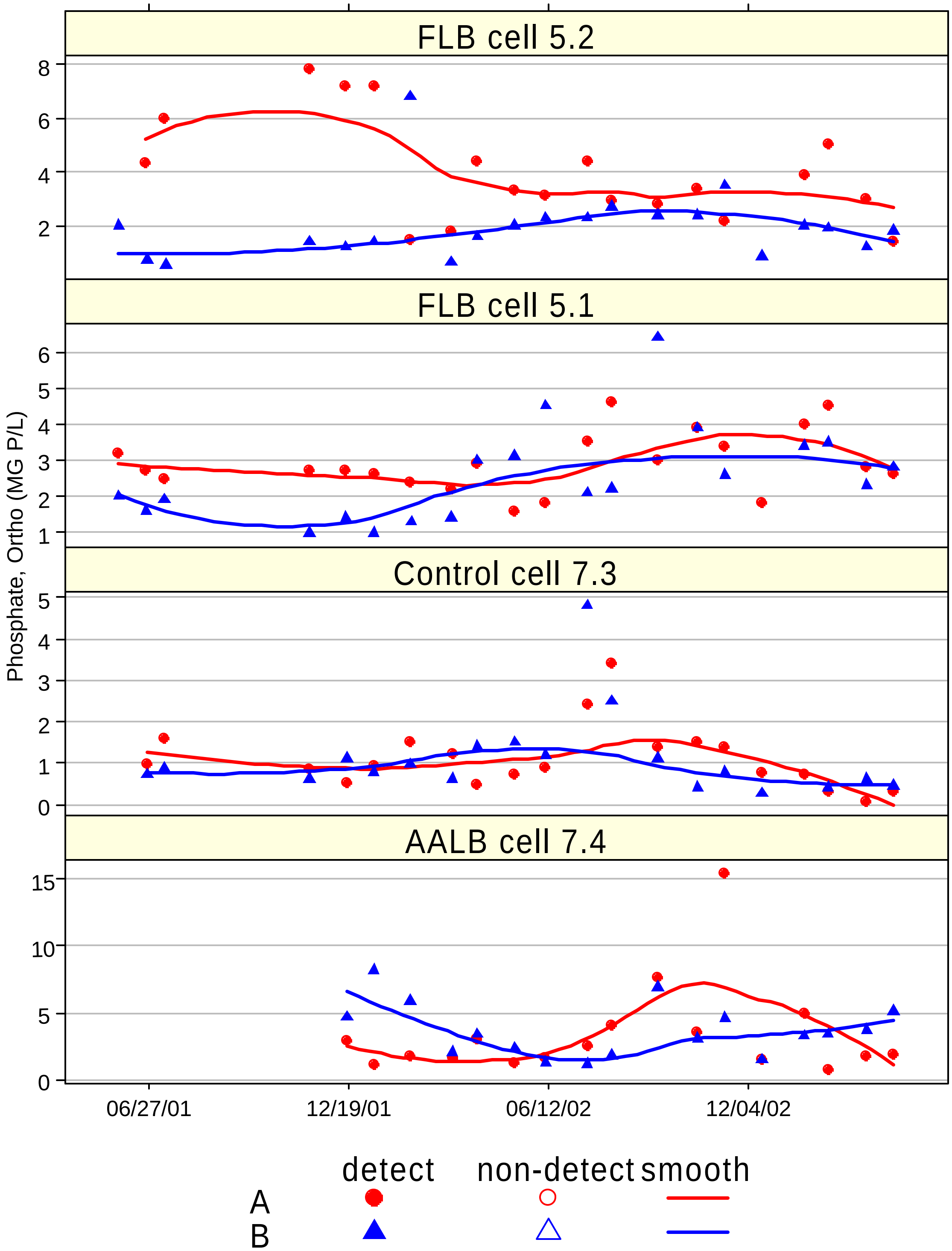


FLB cell 5.2
0.4
0.3
0.2
0.1
0
FLB cell 5.1
0.6
0.4
0.2
0
Control cell 7.3
2
1.5
1
0.5
0
AALB cell 7.4
10
8
6
4
2
0
Nitrite (As N) (MG/L)
06/27/01
12/19/01
06/12/02
12/04/02
detect
non-detect
smooth
A
B

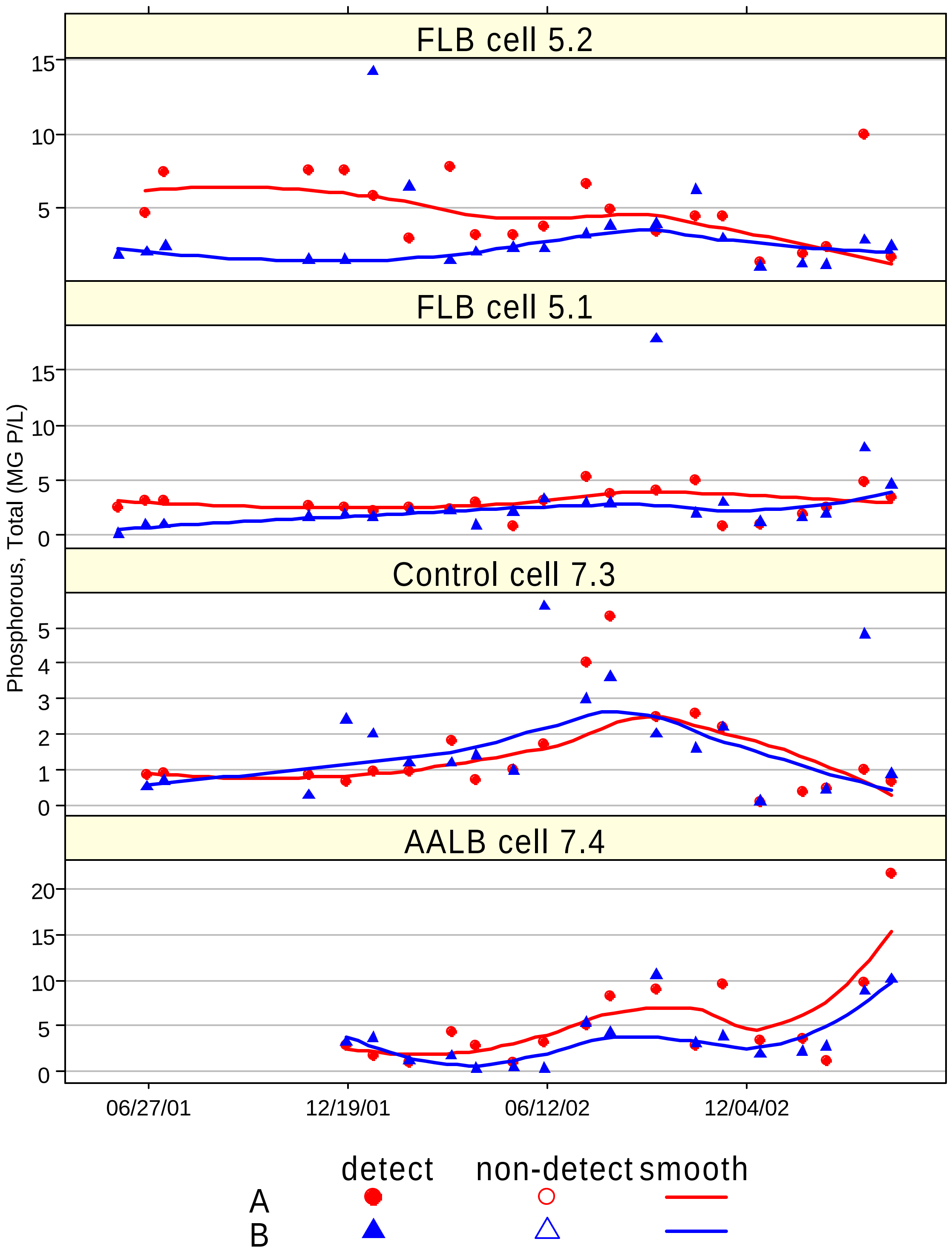
Nitrogen (Nitrate)



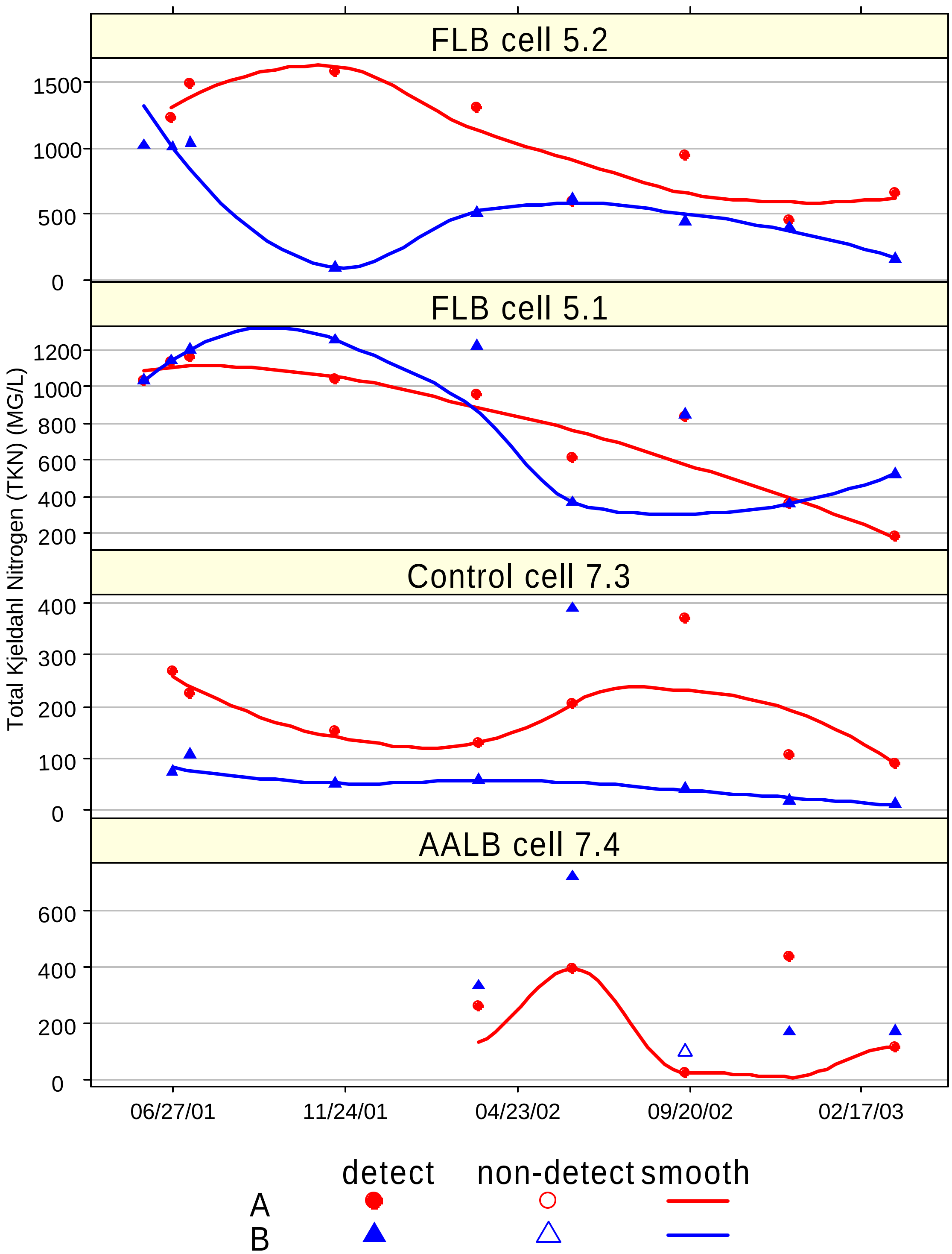
Phosphate, Ortho



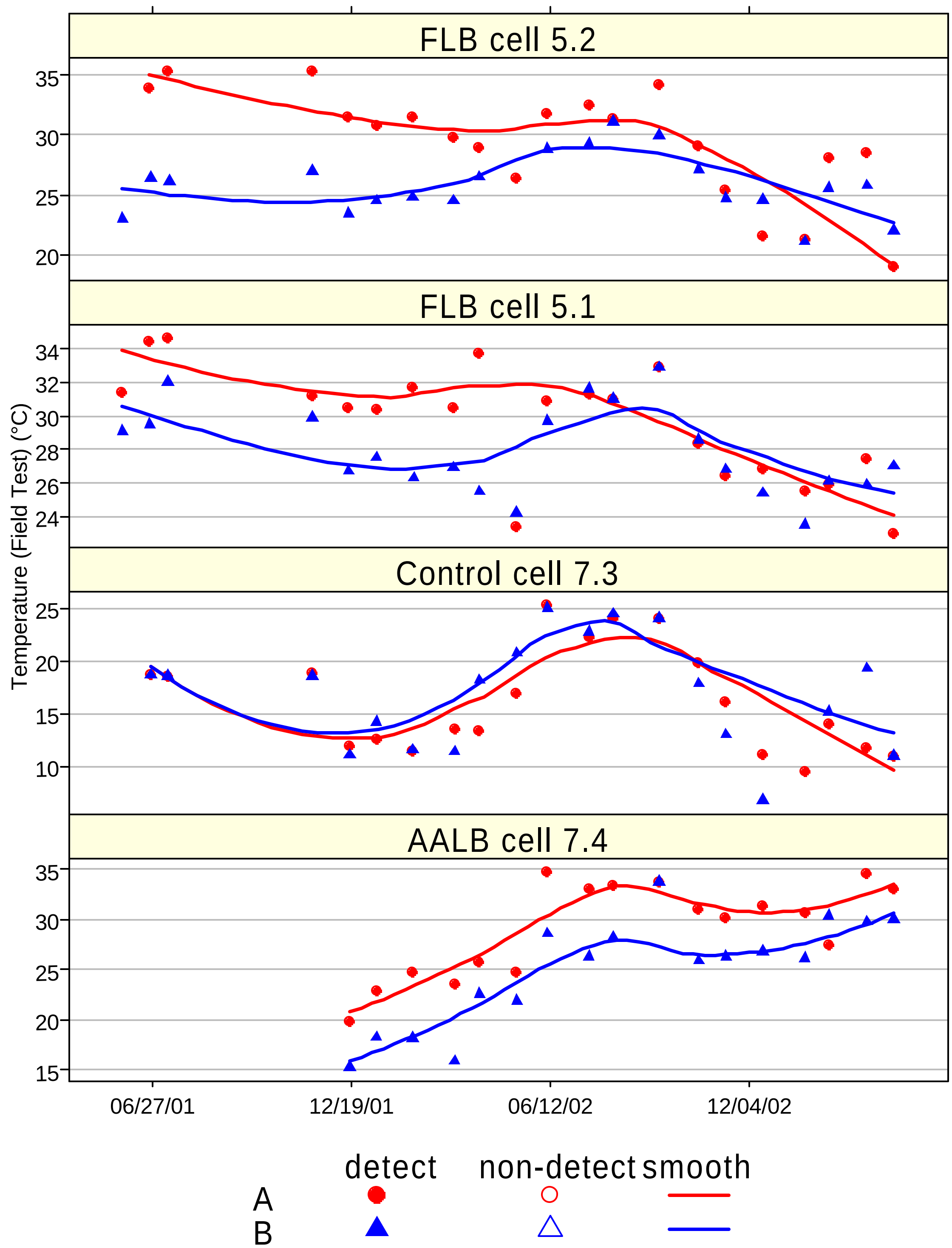
Phosphorous, Total



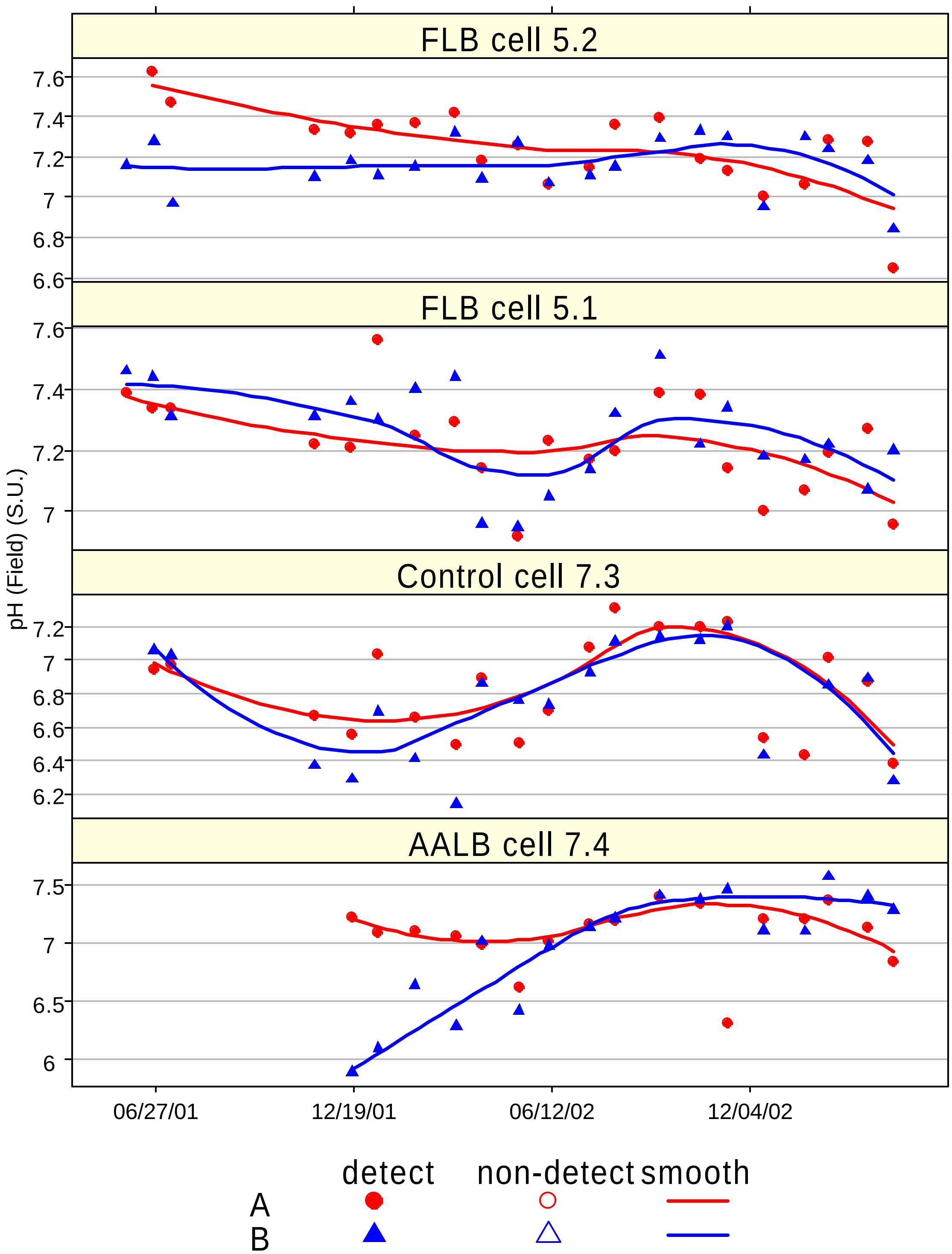
Total Kjeldahl Nitrogen (TKN)



Temperature



pH



FLB cell 5.2
7.6
7.4
7.2
7
6.8
6.6
FLB cell 5.1
7.6
7.4
7.2
7
Control cell 7.3
7.2
7
6.8
6.6
6.4
6.2
AALB cell 7.4
7.5
7
6.5
6
pH (Field) (S.U.)
06/27/01
12/19/01
06/12/02
12/04/02
detect
non-detect
smooth
A
B

Summary

These time plots of the leachate data, in our opinion, give the most representative look into the leachate data. It can be seen that the replicate data (A/B) does not seem to be tightly grouped as would be hoped. It appears, in hindsight, that the (FLB cell 5.1A,FLB cell 5.2B) and (FLB cell 5.1B,FLB cell 5.2A) pairs may be more similar due to similar geometries. Even furthermore, (FLB cell 5.1B,FLB cell 5.2A) could be considered replicates and (FLB cell 5.1A,FLB cell 5.2B) could be considered two independent samples since they share no common boundary and are in somewhat different locations. There is evidence of these kinds of relationships in most of the leachate time plots. Due to this fact, we may try to re-group these samples, in terms of "replicate" status, in future analyses.

Locally weighted regression lines (LOESS) were included to assist the reader in viewing the data. The temporal correlation seems very adequate to justify including smoothed estimates of the data. Statistical tests will still be performed upon the actual data and these lines are only included to help the reader get a qualitative feel for the patterns in the plots.

There are two substantial BOD results, replicates in Control cell 7.3B and AALB cell 7.4B for 12/18/2001. These have been included in the exploratory data analysis and other analyses in lieu of any explanation or reason to disregard them. Although they are influential observations, their removal would probably not have much of an effect on model fitting efforts due to the overall variability of the data.

Influential Data Points to Validate

The following two tables list concentrations that are either extremely large when compared to all cells or large compared to the source cell. These values can have a large influence on statistical analyses and should be investigated further to determine whether they are data entry errors, outliers, or if events can be identified to explain their size.

Parameter	Result	Cell	AorB	Sampdate	Large Relative To
Biochemical Oxygen Demand	1.50E+04	AALB cell 7.4	A	11/14/2002	all cells
	5.44E+04	AALB cell 7.4	B	12/18/2001	all cells
	1.82E+03	Control cell 7.3	A	3/20/2002	rest of cell
	3.14E+04	Control cell 7.3	B	12/18/2001	all cells
	1.85E+03	Control cell 7.3	B	12/18/2001	rest of cell
	1.71E+03	Control cell 7.3	B	5/14/2002	rest of cell
	1.06E+03	FLB cell 5.1	A	5/13/2002	rest of cell
	4.80E+02	FLB cell 5.2	B	9/16/2002	rest of cell
	4.11E+02	FLB cell 5.2	B	10/21/2002	rest of cell
Chemical Oxygen Demand (COD)	3.09E+04	AALB cell 7.4	A	11/14/2002	all cells
	3.17E+03	Control cell 7.3	A	3/20/2002	rest of cell
	5.72E+03	Control cell 7.3	B	12/18/2001	rest of cell
	2.49E+03	Control cell 7.3	B	5/14/2002	rest of cell
Phosphorous, Total	2.16E+01	AALB cell 7.4	A	4/10/2003	all cells
	4.00E+00	Control cell 7.3	A	7/16/2002	rest of cell
	5.30E+00	Control cell 7.3	A	8/7/2002	rest of cell
	7.90E+00	FLB cell 5.1	B	3/18/2003	rest of cell
Total Kjeldahl Nitrogen (TKN)	7.21E+02	AALB cell 7.4	B	6/10/2002	rest of cell
	3.71E+02	Control cell 7.3	A	9/16/2002	rest of cell
	3.90E+02	Control cell 7.3	B	6/10/2002	rest of cell
Ammonia (As N)	2.72E+03	AALB cell 7.4	A	9/16/2002	rest of cell
	1.42E+03	Control cell 7.3	A	7/11/2001	rest of cell
	1.38E+03	Control cell 7.3	A	7/16/2002	rest of cell
	1.16E+03	Control cell 7.3	A	9/16/2002	rest of cell
	1.41E+03	Control cell 7.3	B	7/16/2002	rest of cell
	1.38E+03	Control cell 7.3	B	11/14/2002	rest of cell
	1.92E+04	FLB cell 5.1	A	6/25/2001	all cells
	1.09E+04	FLB cell 5.1	A	12/17/2001	all cells

The following parameter/cell combinations have many large values when compared to the rest of the cells.

Parameter	Cell	AorB
Biochemical Oxygen Demand	AALB cell 7.4	A
Biochemical Oxygen Demand	AALB cell 7.4	B
Chemical Oxygen Demand (COD)	AALB cell 7.4	A
Chemical Oxygen Demand (COD)	AALB cell 7.4	B

LEACHATE REPLICATE ANALYSIS

Analysis of Covariance

An analysis of covariance is performed to compare the A and B pairs of each cell for 5 critical parameters. The comparison of A and B pairs has been performed because the pairs are intended to be replicates within a treatment. However, the A and B pairs are subjected to differing factors like type and amount of waste disposed along with cell geometry. It was discovered that the pairs (FLB cell 5.1A, FLB cell 5.2B) and (FLB cell 5.1B, FLB cell 5.2A) have similar geometries so these pairs were also compared. In future analyses, comparisons may change based upon conclusions about which “replicate” grouping seems most appropriate (see comments in Summary for Leachate Time Plots).

The first step is to fit a polynomial (degree ≤ 3) regression model to all cells. Note that other non-linear models could have been utilized, but for simplicity only polynomial regression was attempted. Next, compare the model fits for A and B within a cell and chose a model that fits both well. Note that this choice may not be the model that fits each one best. However, a common model choice is necessary to perform an analysis of covariance. All model fits and the chosen models (in bold) are shown in the tables following the time and model plots. Many of the model fits are poor with insignificant parameters. The data are, in general, highly variable with small sample sizes. Also, there are many confounding factors that cannot be accounted for directly. These included geometry of cells, age of cells, type of waste in the cells and when the waste was placed in the cells.

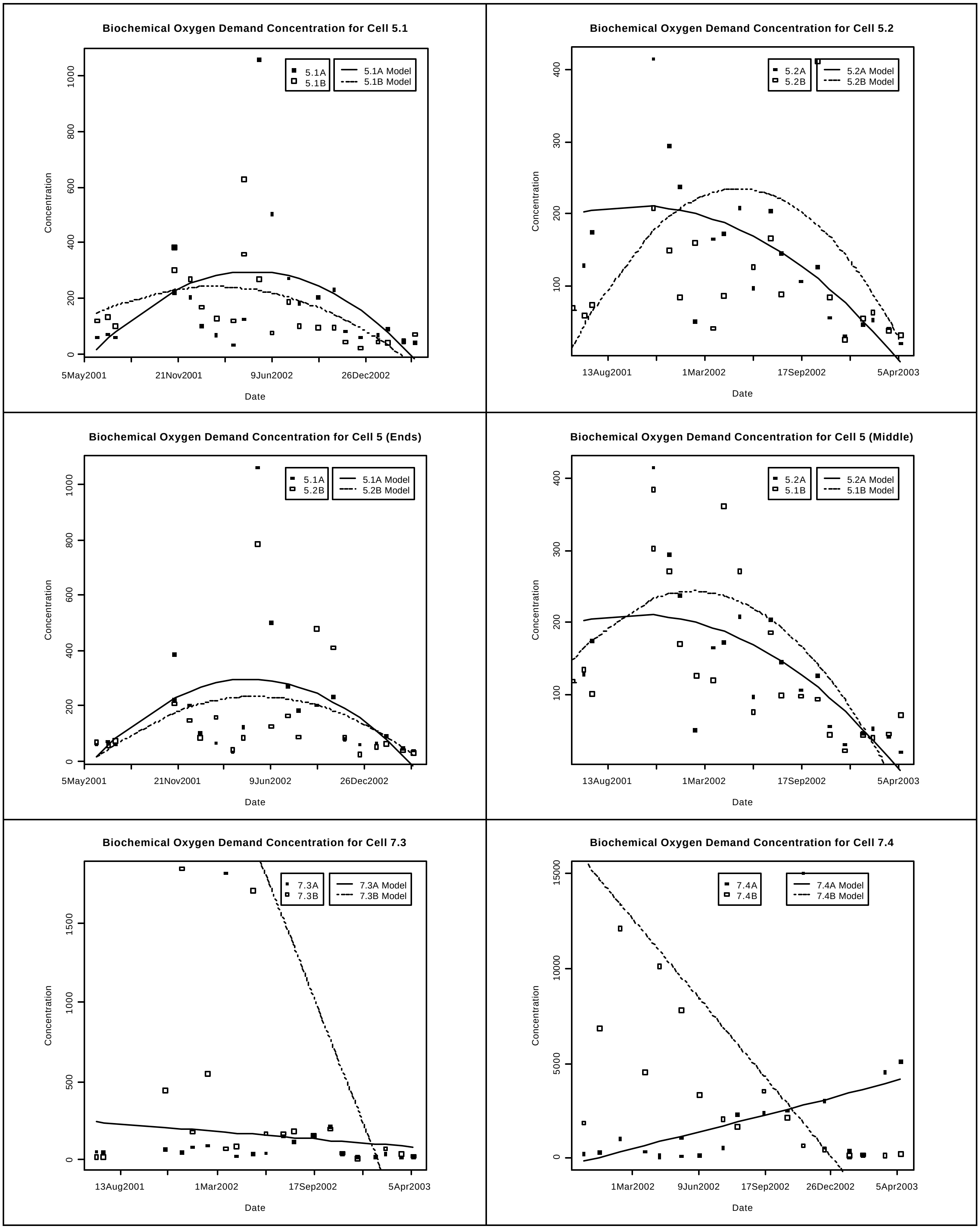
Statistical model comparison is shown in the table below. F-test p-values are provided in the right-side of the table. If all of the p-values are greater than 0.05, then the models are considered to coincide. Models with p-values between 0.05 and 0.10 have also been highlighted as marginally similar. Since many of the model fits are poor, models may be found to be statistically similar when the corresponding model plots look quite different.

Following the analysis of covariance table are time and model plots. The plots provide a means of visually comparing the two models. Note that the chosen model that is plotted may contain insignificant parameters.

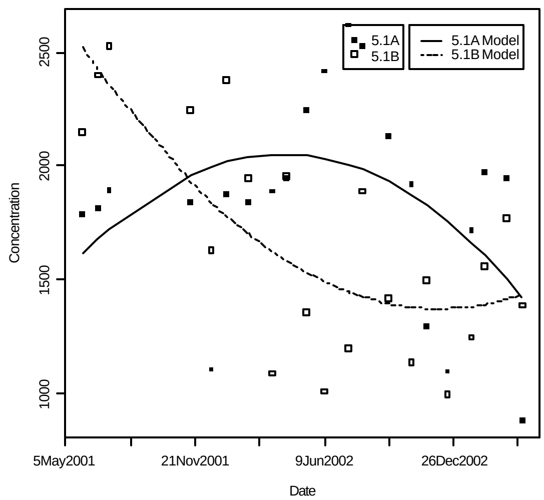
Analysis of Covariance Table

<u>Parameter</u>	**Cells**		**Model**	**Statistically Similar?**	**Term**			
					Cubic	**Quadratic**	**Linear**	**Intercept**
Biochemical Oxygen Demand	FLB cell 5.1A	FLB cell 5.1B	quadratic	yes		0.4285	0.4120	0.5936
	FLB cell 5.2A	FLB cell 5.2B	quadratic	yes		0.3123	0.1218	0.5612
	FLB cell 5.1A	FLB cell 5.2B	quadratic	yes		0.6442	0.8135	0.5925
	FLB cell 5.2a	FLB cell 5.1B	quadratic	yes		0.3412	0.7124	0.3570
	Control cell 7.3A	Control cell 7.3B	linear	yes			0.3466	0.3014
	AALB cell 7.4A	**AALB cell 7.4B**	**linear**	**no**			0.0051	0.1577
Chemical Oxygen Demand	**FLB cell 5.1A**	**FLB cell 5.1B**	**quadratic**	**no**		0.0071	0.0539	0.1670
	FLB cell 5.2A	FLB cell 5.2B	quadratic	yes		0.2199	0.8931	0.3836
	FLB cell 5.1A	**FLB cell 5.2B**	quadratic	no		0.8913	0.8475	0.0048
	FLB cell 5.2a	**FLB cell 5.1B**	quadratic	no		0.0057	0.4406	0.8481
	Control cell 7.3A	Control cell 7.3B	quadratic	yes		0.6555	0.4681	0.3949
	AALB cell 7.4A	**AALB cell 7.4B**	**linear**	**no**			0.0006	0.4461
Total Phosphorous	FLB cell 5.1A	FLB cell 5.1B	linear	yes			0.1490	0.8750
	FLB cell 5.2A	*FLB cell 5.2B*	linear	yes			0.4358	**0.0710**
	FLB cell 5.1A	FLB cell 5.2B	linear	yes			0.5734	0.7361

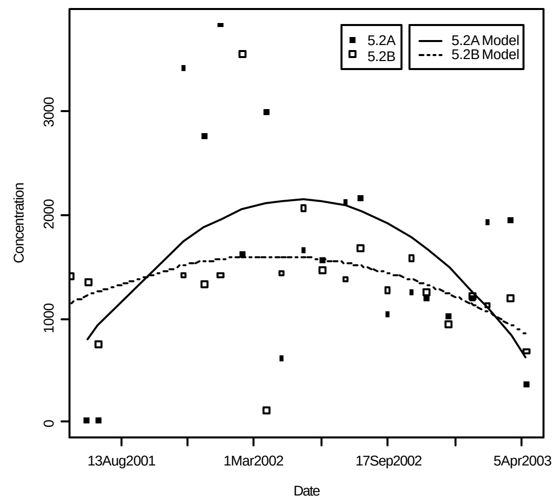
	FLB cell 5.2a	**FLB cell 5.1B**	**linear**	**no**			0.0235	0.1021
	Control cell 7.3A	Control cell 7.3B	quadratic	yes		0.7175	0.5782	0.4107
	AALB cell 7.4A	AALB cell 7.4B	linear	yes			0.3446	0.2134
Total Kjeldahl Nitrogen	FLB cell 5.1A	FLB cell 5.1B	linear	yes			0.7447	0.4744
	FLB cell 5.2A	**FLB cell 5.2B**	**linear**	**no**			0.4873	0.0028
	FLB cell 5.1A	**FLB cell 5.2B**	**linear**	**no**			0.6420	0.0374
	FLB cell 5.2a	FLB cell 5.1B	linear	yes			0.5512	0.2042
	Control cell 7.3A	*Control cell 7.3B*	linear	yes			0.8292	**0.0965**
	AALB cell 7.4A	AALB cell 7.4B	linear	yes			0.5332	0.7070
Ammonia (As N)	*FLB cell 5.1A*	*FLB cell 5.1B*	linear	yes			**0.0841**	0.1729
	FLB cell 5.2A	FLB cell 5.2B	linear	yes			0.9638	0.9366
	FLB cell 5.1A	FLB cell 5.2B	linear	yes			0.1232	0.2320
	FLB cell 5.2a	FLB cell 5.1B	linear	yes			0.5407	0.5333
	Control cell 7.3A	Control cell 7.3B	cubic	yes	0.4256	0.2347	0.2270	0.5138
	AALB cell 7.4A	AALB cell 7.4B	linear	yes			0.8530	0.9939


Biochemical Oxygen Demand Concentration for Cell 5.1
5.1A
5.1B
5.1A Model
5.1B Model
Concentration
0
200
400
600
800
1000
5May2001
21Nov2001
9Jun2002
26Dec2002
Date
Biochemical Oxygen Demand Concentration for Cell 5.2
5.2A
5.2B
5.2A Model
5.2B Model
Concentration
100
200
300
400
13Aug2001
1Mar2002
17Sep2002
5Apr2003
Date
Biochemical Oxygen Demand Concentration for Cell 5 (Ends)
5.1A
5.2B
5.1A Model
5.2B Model
Concentration
0
200
400
600
800
1000
5May2001
21Nov2001
9Jun2002
26Dec2002
Date
Biochemical Oxygen Demand Concentration for Cell 5 (Middle)
5.2A
5.1B
5.2A Model
5.1B Model
Concentration
100
200
300
400
13Aug2001
1Mar2002
17Sep2002
5Apr2003
Date
Biochemical Oxygen Demand Concentration for Cell 7.3
7.3A
7.3B
7.3A Model
7.3B Model
Concentration
0
500
1000
1500
13Aug2001
1Mar2002
17Sep2002
5Apr2003
Date
Biochemical Oxygen Demand Concentration for Cell 7.4
7.4A
7.4B
7.4A Model
7.4B Model
Concentration
0
5000
10000
15000
1Mar2002
9Jun2002
17Sep2002
26Dec2002
5Apr2003
Date

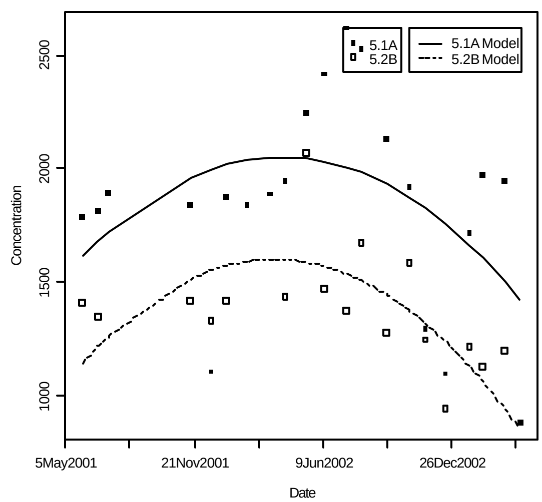
Chemical Oxygen Demand (COD) Concentration for Cell 5.1



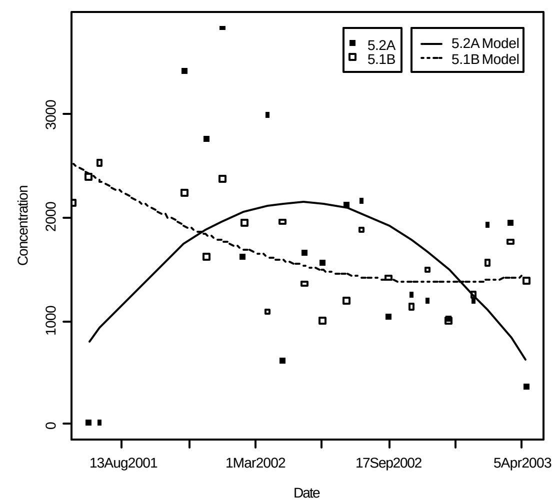
Chemical Oxygen Demand (COD) Concentration for Cell 5.2



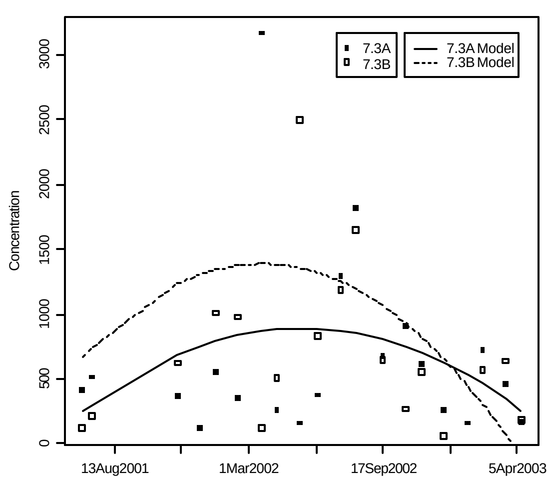
Chemical Oxygen Demand (COD) Concentration for Cell 5 (Ends)



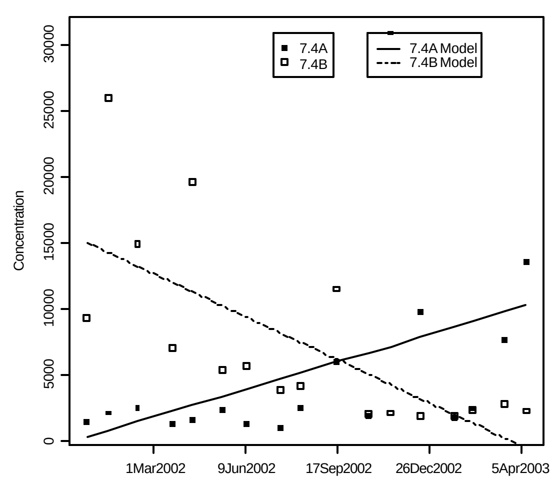
Chemical Oxygen Demand (COD) Concentration for Cell 5 (Middle)



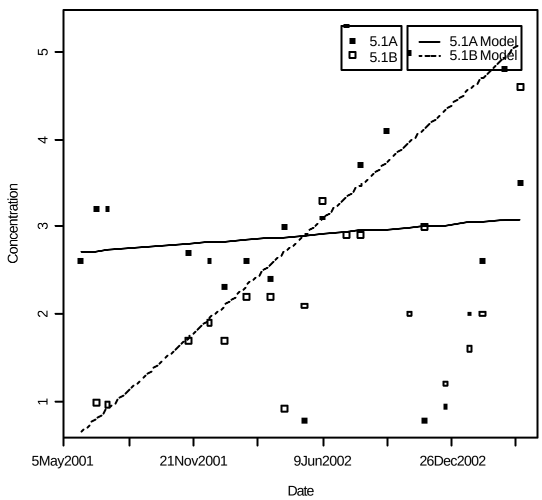
Chemical Oxygen Demand (COD) Concentration for Cell 7.3



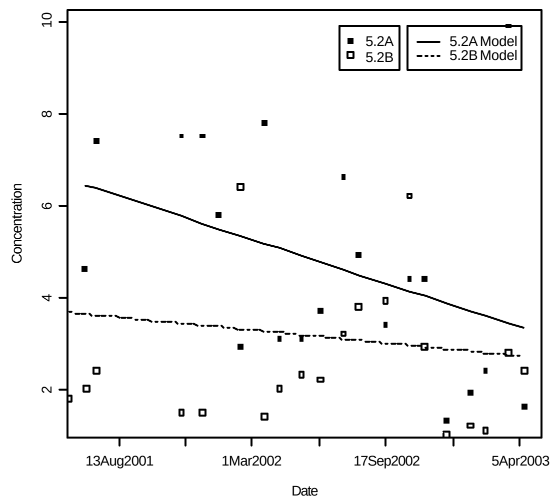
Chemical Oxygen Demand (COD) Concentration for Cell 7.4



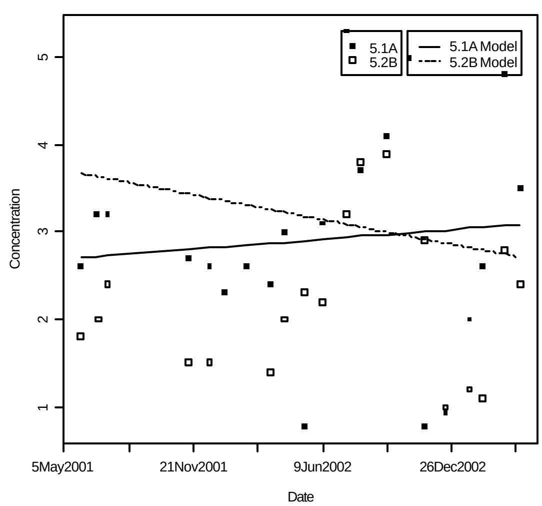
Phosphorous, Total Concentration for Cell 5.1



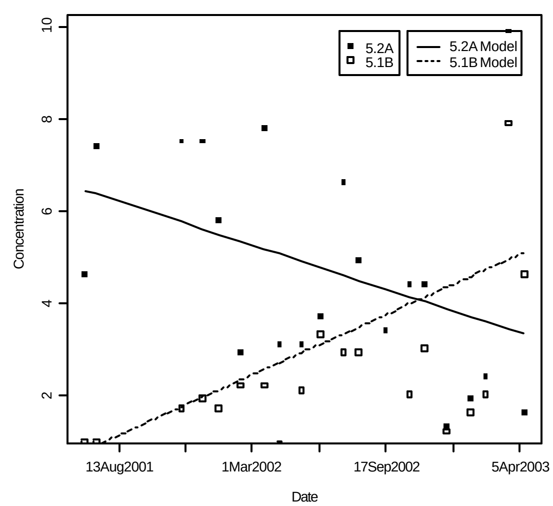
Phosphorous, Total Concentration for Cell 5.2



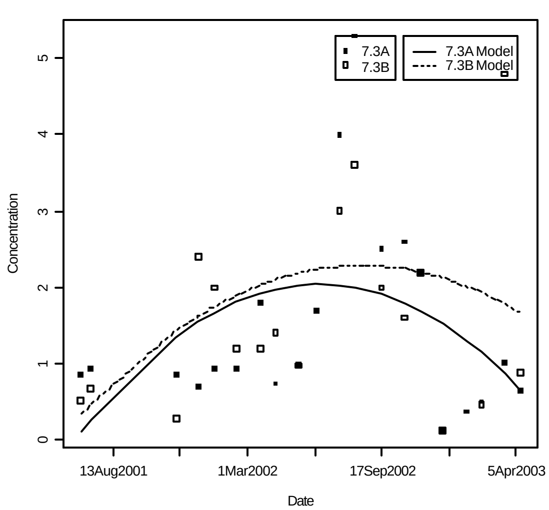
Phosphorous, Total Concentration for Cell 5 (Ends)



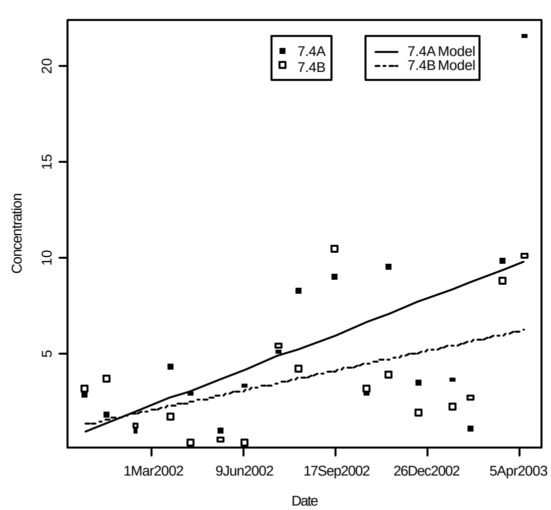
Phosphorous, Total Concentration for Cell 5 (Middle)

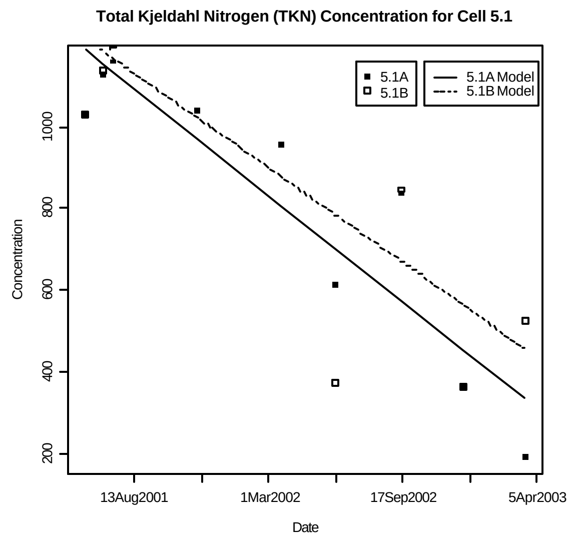


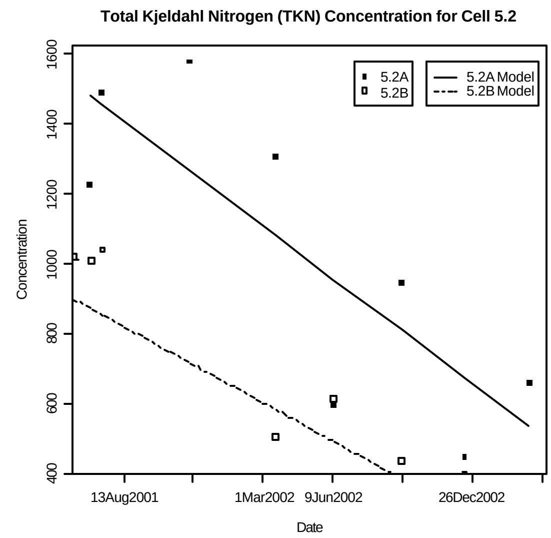
Phosphorous, Total Concentration for Cell 7.3

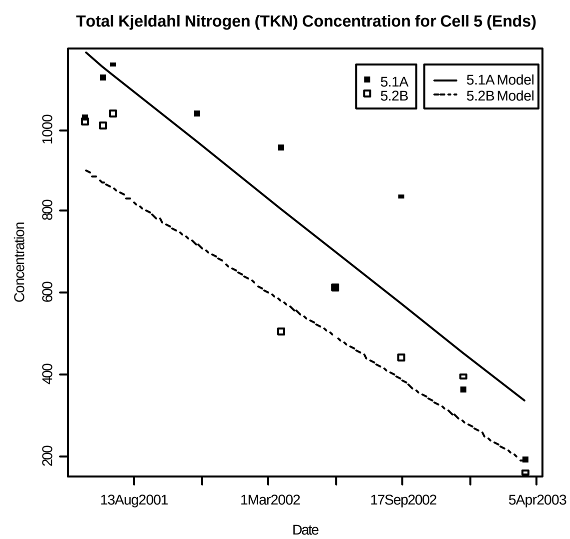


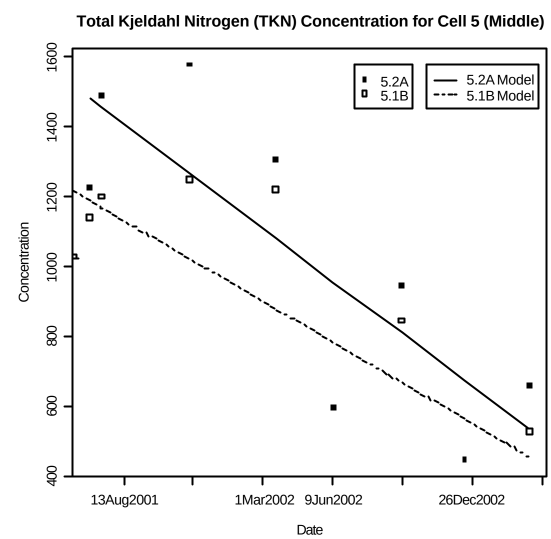
Phosphorous, Total Concentration for Cell 7.4

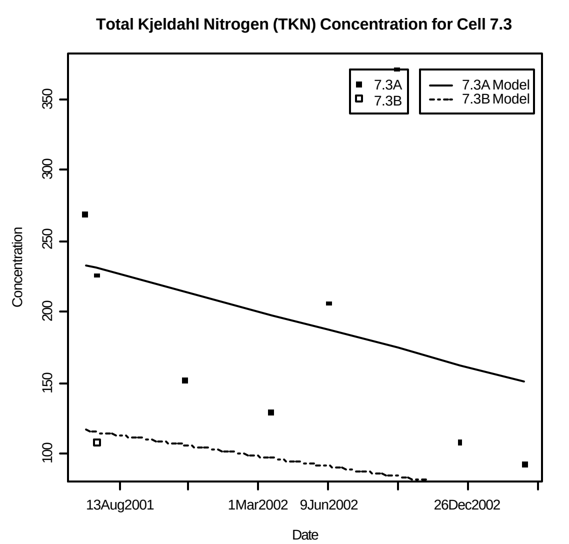


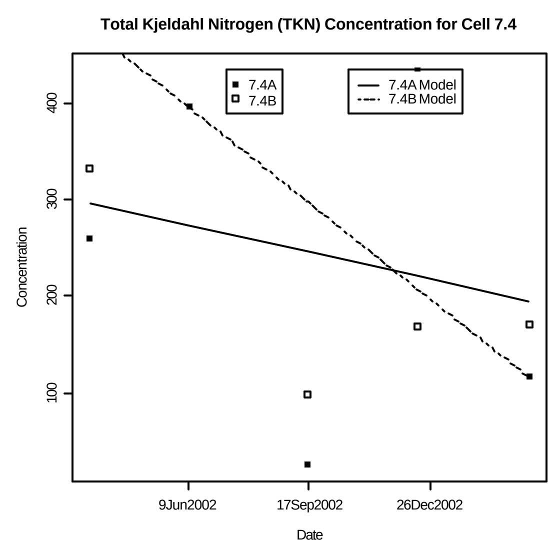

Total Kjeldahl Nitrogen (TKN) Concentration for Cell 5.1
5.1A
5.1B
5.1A Model
5.1B Model
Concentration
Date
13Aug2001
1Mar2002
17Sep2002
5Apr2003


Total Kjeldahl Nitrogen (TKN) Concentration for Cell 5.2
5.2A
5.2B
5.2A Model
5.2B Model
Concentration
Date
13Aug2001
1Mar2002
9Jun2002
26Dec2002

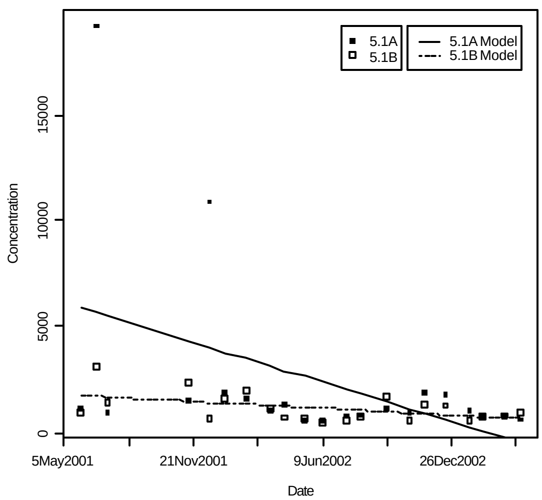

Total Kjeldahl Nitrogen (TKN) Concentration for Cell 5 (Ends)
5.1A
5.2B
5.1A Model
5.2B Model
Concentration
Date
13Aug2001
1Mar2002
17Sep2002
5Apr2003


Total Kjeldahl Nitrogen (TKN) Concentration for Cell 5 (Middle)
5.2A
5.1B
5.2A Model
5.1B Model
Concentration
Date
13Aug2001
1Mar2002
9Jun2002
26Dec2002

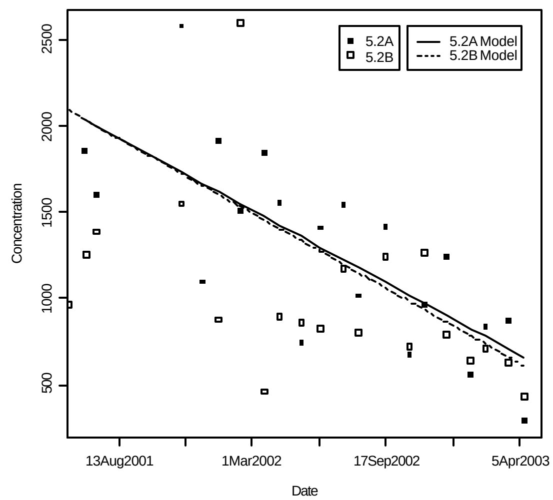

Total Kjeldahl Nitrogen (TKN) Concentration for Cell 7.3
7.3A
7.3B
7.3A Model
7.3B Model
Concentration
Date
13Aug2001
1Mar2002
9Jun2002
26Dec2002


Total Kjeldahl Nitrogen (TKN) Concentration for Cell 7.4
7.4A
7.4B
7.4A Model
7.4B Model
Concentration
Date
9Jun2002
17Sep2002
26Dec2002

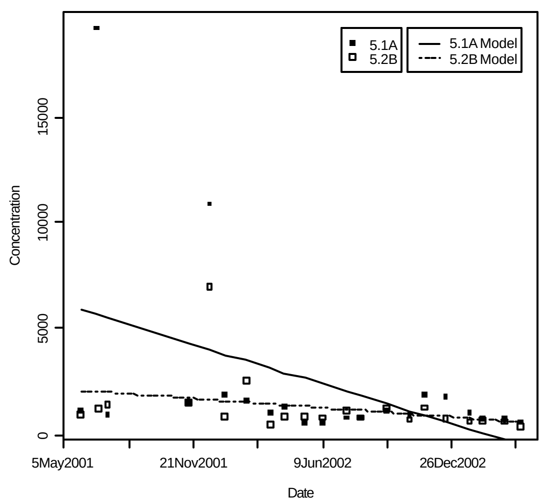
Ammonia (As N) Concentration for Cell 5.1



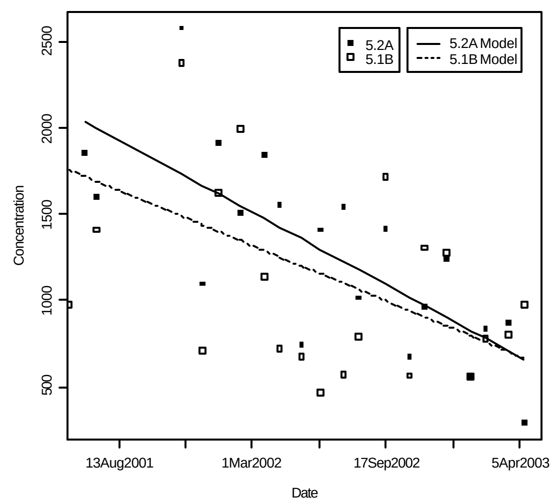
Ammonia (As N) Concentration for Cell 5.2



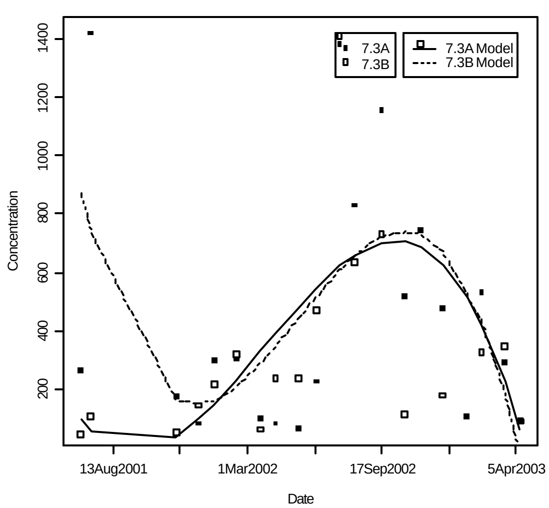
Ammonia (As N) Concentration for Cell 5 (Ends)



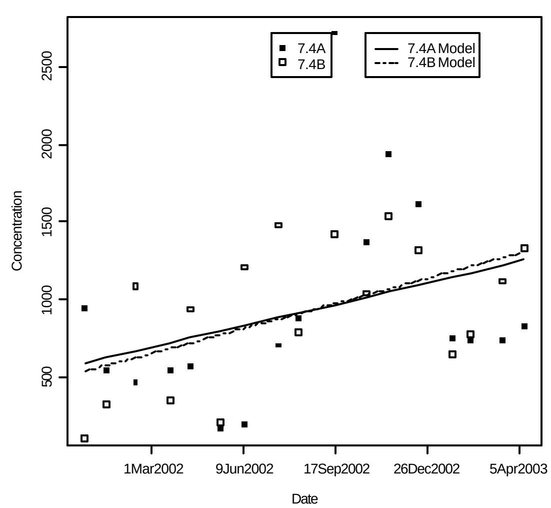
Ammonia (As N) Concentration for Cell 5 (Middle)



Ammonia (As N) Concentration for Cell 7.3



Ammonia (As N) Concentration for Cell 7.4



Biochemical Oxygen Demand

		FLB cell 5.1A L01		FLB cell 5.1B L01	
		coefficient	**p-value**	coefficient	p-value
linear	intercept	2.152412e+02	0.04552217	2.682627e+02	0.0001481634
	date	-7.337726e-02	0.76794800	-2.890203e-01	0.0553831481
quadratic	**intercept**	**1.827701e+01**	**0.88736979**	**1.473795e+02**	**0.0584492734**
	date	**1.696082e+00**	**0.05274789**	**7.663082e-01**	**0.1151858269**
	date^2	**-2.576048e-03**	**0.03722919**	**-1.532262e-03**	**0.0284958364**
cubic	intercept	3.154714e+01	0.83555604	7.426527e+01	0.3593276353
	date	1.379486e+00	0.48586123	2.510360e+00	0.0232186664
	date^2	-1.338671e-03	0.84888488	-8.369213e-03	0.0334183914
	date^3	-1.231015e-06	0.85813385	6.814990e-06	0.0727081641

		FLB cell 5.2A L01		FLB cell 5.2B L01	
		coefficient	p-value	coefficient	p-value
linear	intercept	2.588700e+02	1.675535e-06	1.559619e+02	0.08466699
	date	-3.346164e-01	1.732076e-03	2.602369e-05	0.99989973
quadratic	**intercept**	**2.024532e+02**	**8.140932e-04**	**1.455682e+01**	**0.89427285**
	date	**1.587610e-01**	**6.232715e-01**	**1.285332e+00**	**0.07736977**
	date^2	**-7.296590e-04**	**1.242635e-01**	**-1.876052e-03**	**0.06691669**
cubic	intercept	1.642517e+02	6.746645e-03	6.282264e+01	0.61710203
	date	1.146506e+00	1.061819e-01	3.714552e-02	0.98229640
	date^2	-4.744217e-03	7.238006e-02	3.008179e-03	0.61900326
	date^3	4.138439e-06	1.177996e-01	-4.841674e-06	0.41606637

		Control cell 7.3A L01		Control cell 7.3B L01	
		coefficient	p-value	coefficient	p-value
linear	**intercept**	**2.436908e+02**	**0.2221977**	**4.552255e+03**	**0.1593952**
	date	**-2.445069e-01**	**0.6113035**	**-7.852682e+00**	**0.3235841**
quadratic	intercept	3.965700e+01	0.8840587	3.376253e+03	0.4712576
	date	1.546337e+00	0.3780156	2.273288e+00	0.9395064
	date^2	-2.654637e-03	0.2907304	-1.487198e-02	0.7260773
cubic	intercept	-1.974563e+01	0.9491376	4.574563e+02	0.9293698
	date	3.095429e+00	0.4358343	7.216667e+01	0.2679709
	date^2	-8.968965e-03	0.5394232	-2.989309e-01	0.2127126
	date^3	6.522872e-06	0.6598928	2.936991e-04	0.2281026

		AALB cell 7.4A L01		AALB cell 7.4B L01	
		coefficient	p-value	coefficient	p-value
linear	**intercept**	**-1.494479e+02**	**0.9146097**	**1.567017e+04**	**0.003388943**
	date	**8.937710e+00**	**0.0867887**	**-4.169637e+01**	**0.023164682**
quadratic	intercept	-6.318798e+02	0.7647328	2.076381e+04	0.002358366
	date	1.520903e+01	0.4677170	-1.227301e+02	0.055485451
	date^2	-1.291843e-02	0.7557589	1.756980e-01	0.174735767
cubic	intercept	3.850463e+02	0.8816165	2.311238e+04	0.003205906
	date	-1.322407e+01	0.7722729	-2.170226e+02	0.132124827
	date^2	1.423817e-01	0.5294259	7.182375e-01	0.330033545
	date^3	-2.197728e-04	0.4856335	-7.767112e-04	0.451624289

Chemical Oxygen Demand (COD)

		FLB cell 5.1A L01		FLB cell 5.1B L01	
		coefficient	p-value	coefficient	p-value
linear	intercept	1.960465e+03	1.081922e-08	2.235893e+03	3.552959e-11
	date	-3.061233e-01	5.386668e-01	-1.573900e+00	8.013883e-04
quadratic	**intercept**	**1.615873e+03**	**6.124507e-06**	**2.520544e+03**	**3.802319e-10**
	date	**2.834956e+00**	**9.905660e-02**	**-4.168465e+00**	**5.202189e-03**
	date^2	**-4.588793e-03**	**6.006205e-02**	**3.790489e-03**	**5.415787e-02**
cubic	intercept	1.825067e+03	4.699406e-06	2.365736e+03	7.849645e-09
	date	-2.632638e+00	4.884627e-01	-1.195621e-01	9.689652e-01
	date^2	1.684489e-02	2.259622e-01	-1.208195e-02	2.840335e-01
	date^3	-2.126205e-05	1.235399e-01	1.574490e-05	1.590089e-01

		FLB cell 5.2A L01		FLB cell 5.2B L01	
		coefficient	p-value	coefficient	p-value
linear	intercept	1.840461e+03	0.002178118	1.536272e+03	4.519746e-05
	date	-5.616490e-01	0.661432084	-4.643965e-01	5.132532e-01
quadratic	**intercept**	**8.047374e+02**	**0.232099393**	**1.147920e+03**	**7.569550e-03**
	date	**8.495986e+00**	**0.055486304**	**3.065543e+00**	**2.223960e-01**
	date^2	**-1.339539e-02**	**0.035815796**	**-5.152352e-03**	**1.471131e-01**
cubic	intercept	5.576066e+01	0.928185709	1.139109e+03	2.025952e-02
	date	2.786167e+01	0.002354332	3.293389e+00	5.870335e-01
	date^2	-9.210465e-02	0.005135538	-6.043928e-03	7.811988e-01
	date^3	8.113807e-05	0.012548053	8.838069e-07	9.668344e-01

		Control cell 7.3A L01		Control cell 7.3B L01	
		coefficient	p-value	coefficient	p-value
linear	intercept	7.102012e+02	0.05999102	1.428613e+03	0.03666348
	date	-1.193484e-01	0.89215459	-1.331828e+00	0.41302080
quadratic	**intercept**	**2.456102e+02**	**0.61726719**	**6.683128e+02**	**0.44712134**
	date	**3.958456e+00**	**0.21549391**	**5.385694e+00**	**0.33984764**
	date^2	**-6.044686e-03**	**0.18588644**	**-1.005476e-02**	**0.21877505**
cubic	intercept	3.643681e+02	0.51560667	1.432952e+02	0.88009151
	date	8.615070e-01	0.90310030	1.911237e+01	0.12987300
	date^2	6.578941e-03	0.80137794	-6.599695e-02	0.15513754
	date^3	-1.304055e-05	0.62496324	5.766683e-05	0.21701552

		AALB cell 7.4A L01		AALB cell 7.4B L01	
		coefficient	p-value	coefficient	p-value
linear	**intercept**	**2.728821e+02**	**0.93308625**	**1.500991e+04**	**1.144936e-05**
	date	**2.090255e+01**	**0.08442847**	**-3.249839e+01**	**1.337172e-03**
quadratic	intercept	2.807360e+02	0.95199798	1.775043e+04	6.699188e-05
	date	2.079518e+01	0.65019472	-6.996677e+01	4.120704e-02
	date^2	2.239602e-04	0.99805724	7.814792e-02	2.328388e-01
cubic	intercept	2.533684e+03	0.65754826	1.702006e+04	8.242883e-04
	date	-4.896104e+01	0.65094440	-4.735300e+01	5.360385e-01
	date^2	3.802693e-01	0.48384465	-4.505629e-02	9.053947e-01
	date^3	-5.314646e-04	0.47747192	1.722917e-04	7.418435e-01

Phosphorous, Total

		FLB cell 5.1A L01		FLB cell 5.1B L01	
		coefficient	p-value	coefficient	p-value
linear	**intercept**	**2.707463e+00**	**0.0001475468**	**6.418077e-01**	**0.6942815**
	date	**5.626158e-04**	**0.6850799049**	**6.557450e-03**	**0.1034484**
quadratic	intercept	2.883161e+00	0.0018398618	1.223737e-01	0.9565856
	date	-1.038930e-03	0.8384629711	1.129205e-02	0.4332161
	date^2	2.339693e-06	0.7437386096	-6.916933e-06	0.7304152
cubic	intercept	2.928984e+00	0.0053724566	6.105435e-01	0.8146521
	date	-2.236583e-03	0.8579301840	-1.475719e-03	0.9662528
	date^2	7.034650e-06	0.8759199590	4.313505e-05	0.7321341
	date^3	-4.657362e-09	0.9158594354	-4.964979e-08	0.6874593

		FLB cell 5.2A L01		FLB cell 5.2B L01	
		coefficient	p-value	coefficient	p-value
linear	**intercept**	**6.426692e+00**	**1.403425e-05**	**3.672043e+00**	**0.01329640**
	date	**-4.754063e-03**	**9.184472e-02**	**-1.416524e-03**	**0.66363669**
quadratic	intercept	6.755890e+00	4.716200e-04	2.188115e+00	0.23744612
	date	-7.632967e-03	4.543398e-01	1.207169e-02	0.30265865
	date^2	4.257629e-06	7.675323e-01	-1.968761e-05	0.23295379
cubic	intercept	6.001566e+00	3.341393e-03	1.493954e+00	0.47723110
	date	1.187098e-02	5.984809e-01	3.002315e-02	0.28994542
	date^2	-7.501358e-05	3.703287e-01	-8.993276e-05	0.37618268
	date^3	8.171736e-08	3.372653e-01	6.963309e-08	0.48161812

		Control cell 7.3A L01		Control cell 7.3B L01	
		coefficient	p-value	coefficient	p-value
linear	intercept	1.290169e+00	0.05730722	1.178021e+00	0.1229711
	date	5.324213e-04	0.73655511	1.886232e-03	0.3167403
quadratic	**intercept**	**1.013494e-01**	**0.90247044**	**3.305437e-01**	**0.7430964**
	date	**1.096692e-02**	**0.04991549**	**9.373992e-03**	**0.1579260**
	date^2	**-1.546745e-05**	**0.05206245**	**-1.120765e-05**	**0.2348907**
cubic	intercept	8.479099e-01	0.32103152	3.526714e-01	0.7608092
	date	-8.501764e-03	0.43097181	8.795457e-03	0.5539467
	date^2	6.388979e-05	0.11964919	-8.849872e-06	0.8713087
	date^3	-8.197817e-08	0.05458430	-2.430469e-09	0.9650235

		AALB cell 7.4A L01		AALB cell 7.4B L01	
		coefficient	p-value	coefficient	p-value
linear	**intercept**	**9.293295e-01**	**0.65199414**	**1.273296e+00**	**0.35193662**
	date	**1.855459e-02**	**0.02026386**	**1.034462e-02**	**0.04345766**
quadratic	intercept	2.915159e+00	0.31396703	2.565731e+00	0.18332603
	date	-8.595683e-03	0.75786922	-7.325562e-03	0.68945135
	date^2	5.662741e-05	0.32110025	3.685475e-05	0.32528984
cubic	intercept	1.563474e-01	0.96156958	2.235548e+00	0.34352471
	date	7.682319e-02	0.22462179	2.897617e-03	0.94735924
	date^2	-4.087511e-04	0.19715947	-1.884311e-05	0.93144676
	date^3	6.507966e-07	0.14004323	7.788924e-08	0.79646740

Total Kjeldahl Nitrogen (TKN)

		FLB cell 5.1A L01		FLB cell 5.1B L01	
		coefficient	p-value	coefficient	p-value
linear	**intercept**	**1.186743e+03**	**1.545508e-06**	**1.216155e+03**	**4.280723e-05**
	date	**-1.301889e+00**	**5.516811e-04**	**-1.160246e+00**	**1.584045e-02**
quadratic	intercept	1.101968e+03	8.686775e-06	1.170280e+03	4.503441e-04
	date	-1.408898e-02	9.838737e-01	-4.633607e-01	7.560703e-01
	date^2	-2.098476e-03	9.224937e-02	-1.135579e-03	6.293948e-01
cubic	intercept	1.104722e+03	9.831374e-05	1.052960e+03	1.960242e-03
	date	-1.180686e-01	9.527674e-01	3.964969e+00	2.992721e-01
	date^2	-1.667458e-03	8.293180e-01	-1.949198e-02	2.014800e-01
	date^3	-4.381939e-07	9.549029e-01	1.866199e-05	2.199153e-01

		FLB cell 5.2A L01		FLB cell 5.2B L01	
		coefficient	p-value	coefficient	p-value
linear	**intercept**	**1.482229e+03**	**8.902959e-05**	**8.991622e+02**	**0.0003929878**
	date	**-1.504524e+00**	**1.289419e-02**	**-1.091677e+00**	**0.0252868669**
quadratic	intercept	1.451165e+03	8.733119e-04	9.819408e+02	0.0012002987
	date	-1.054577e+00	5.503233e-01	-2.340766e+00	0.1544070832
	date^2	-7.506798e-04	7.872231e-01	2.033163e-03	0.4011545800
cubic	intercept	1.334024e+03	2.082921e-03	1.148830e+03	0.0004901504
	date	4.289159e+00	2.813821e-01	-8.540944e+00	0.0266411505
	date^2	-2.419000e-02	1.588921e-01	2.769309e-02	0.0478667655
	date^3	2.491795e-05	1.648856e-01	-2.607333e-05	0.0582659710

		Control cell 7.3A L01		Control cell 7.3B L01	
		coefficient	p-value	coefficient	p-value
linear	**intercept**	**2.329992e+02**	**0.006583895**	**1.163771e+02**	**0.1885619**
	date	**-1.302736e-01**	**0.431311936**	**-7.249440e-02**	**0.7436343**
quadratic	intercept	2.193082e+02	0.029986841	6.413407e+01	0.5132520
	date	6.935795e-02	0.910668726	6.892750e-01	0.3908422
	date^2	-3.339230e-04	0.737619354	-1.274209e-03	0.3284838
cubic	intercept	2.629507e+02	0.014521089	7.794385e+01	0.5094423
	date	-1.954824e+00	0.171120388	4.876317e-02	0.9815769
	date^2	8.569131e-03	0.147270229	1.542984e-03	0.8578281
	date^3	-9.482668e-06	0.132005299	-3.000600e-06	0.7416922

		AALB cell 7.4A L01		AALB cell 7.4B L01	
		coefficient	p-value	coefficient	p-value
linear	**intercept**	**2.968319e+02**	**0.1422521**	**4.751919e+02**	**0.07980778**
	date	**-2.797538e-01**	**0.7078643**	**-9.854460e-01**	**0.31771615**
quadratic	intercept	2.820791e+02	0.3322031	4.746016e+02	0.22190046
	date	5.367207e-02	0.9872122	-9.721032e-01	0.81326064
	date^2	-9.208126e-04	0.9175455	-3.684848e-05	0.99728299
cubic	intercept	3.072219e+02	0.5206202	3.737667e+02	0.42000641
	date	-1.790548e+00	0.8795787	6.424126e+00	0.57964067
	date^2	1.309786e-02	0.8730695	-5.625863e-02	0.50601183
	date^3	-2.561497e-05	0.8625165	1.027286e-04	0.50167999

Ammonia (As N)

		FLB cell 5.1A L01		FLB cell 5.1B L01	
		coefficient	p-value	coefficient	p-value
linear	**intercept**	**5.891555e+03**	**0.004380627**	**1.757537e+03**	**3.485958e-06**
	date	**-9.398683e+00**	**0.043475747**	**-1.605124e+00**	**2.306600e-02**
quadratic	intercept	7.657295e+03	0.005736417	1.985035e+03	4.008765e-05
	date	-2.549405e+01	0.117999149	-3.678752e+00	1.332392e-01
	date^2	2.351368e-02	0.294740536	3.029433e-03	3.682352e-01
cubic	intercept	7.502048e+03	0.017110290	1.870821e+03	3.792349e-04
	date	-2.143644e+01	0.580445833	-6.915495e-01	9.045288e-01
	date^2	7.607298e-03	0.956424707	-8.680947e-03	6.770770e-01
	date^3	1.577901e-05	0.907820805	1.161628e-05	5.699373e-01

		FLB cell 5.2A L01		FLB cell 5.2B L01	
		coefficient	p-value	coefficient	p-value
linear	**intercept**	**2.037352e+03**	**1.323264e-09**	**2.088572e+03**	**0.002769706**
	date	**-2.102609e+00**	**1.555545e-04**	**-2.175365e+00**	**0.149737373**
quadratic	intercept	1.861285e+03	1.087967e-06	1.646251e+03	0.062300131
	date	-5.628595e-01	7.303572e-01	1.845129e+00	0.729955954
	date^2	-2.277145e-03	3.327963e-01	-5.868373e-03	0.436791548
cubic	intercept	1.805746e+03	1.100234e-05	1.036460e+03	0.271721227
	date	8.731488e-01	8.137686e-01	1.761472e+01	0.166983484
	date^2	-8.113609e-03	5.541618e-01	-6.757577e-02	0.142364982
	date^3	6.016566e-06	6.648267e-01	6.116972e-05	0.172571765

		Control cell 7.3A L01		Control cell 7.3B L01	
		coefficient	p-value	coefficient	p-value
linear	intercept	4.919822e+02	0.032316700	1.471974e+02	0.45166176
	date	-8.922344e-02	0.865743229	6.559115e-01	0.19081172
quadratic	intercept	5.113659e+02	0.111779808	-1.258665e+02	0.62786942
	date	-2.593578e-01	0.895440894	3.068528e+00	0.07740272
	date^2	2.521967e-04	0.928534768	-3.611196e-03	0.14120338
cubic	**intercept**	**8.705869e+02**	**0.006949358**	**9.829742e+01**	**0.71117510**
	date	**-9.627064e+00**	**0.015995287**	**-2.792277e+00**	**0.41441411**
	date^2	**3.843636e-02**	**0.010191162**	**2.027414e-02**	**0.11997870**
	date^3	**-3.944528e-05**	**0.009657178**	**-2.462170e-05**	**0.06724930**

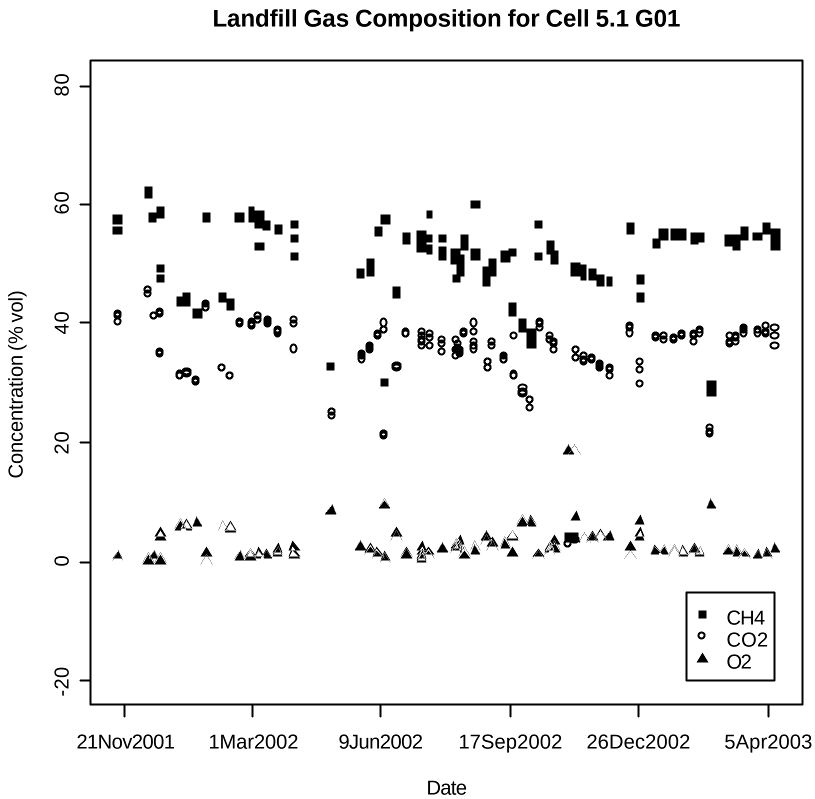
		AALB cell 7.4A L01		AALB cell 7.4B L01	
		coefficient	p-value	coefficient	p-value
linear	**intercept**	**5.906813e+02**	**0.06133527**	**5.345041e+02**	**0.01109482**
	date	**1.383019e+00**	**0.20084230**	**1.611618e+00**	**0.02616511**
quadratic	intercept	2.714398e+02	0.50847802	2.400521e+02	0.33197643
	date	5.747689e+00	0.16455342	5.637367e+00	0.03033601
	date^2	-9.103408e-03	0.26791563	-8.396519e-03	0.09642544
cubic	intercept	8.731121e+02	0.04565582	1.866690e+02	0.53913615
	date	-1.288140e+01	0.10869700	7.290225e+00	0.21575358
	date^2	9.239150e-02	0.02785519	-1.740161e-02	0.54445124
	date^3	-1.419329e-04	0.01618144	1.259294e-05	0.74881839

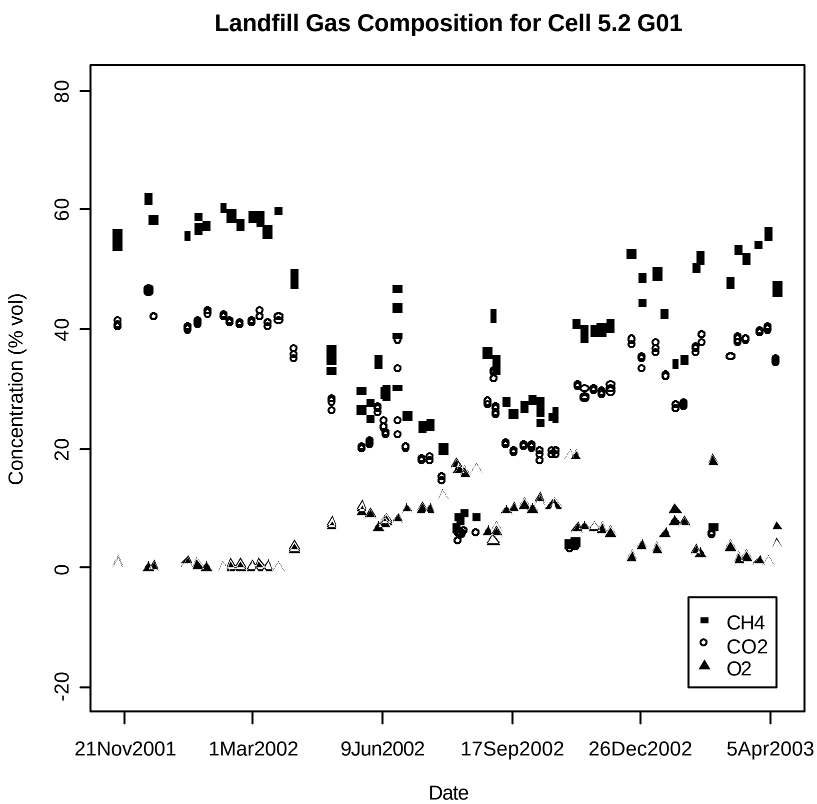
FIELD GAS TIME PLOTS

Summary

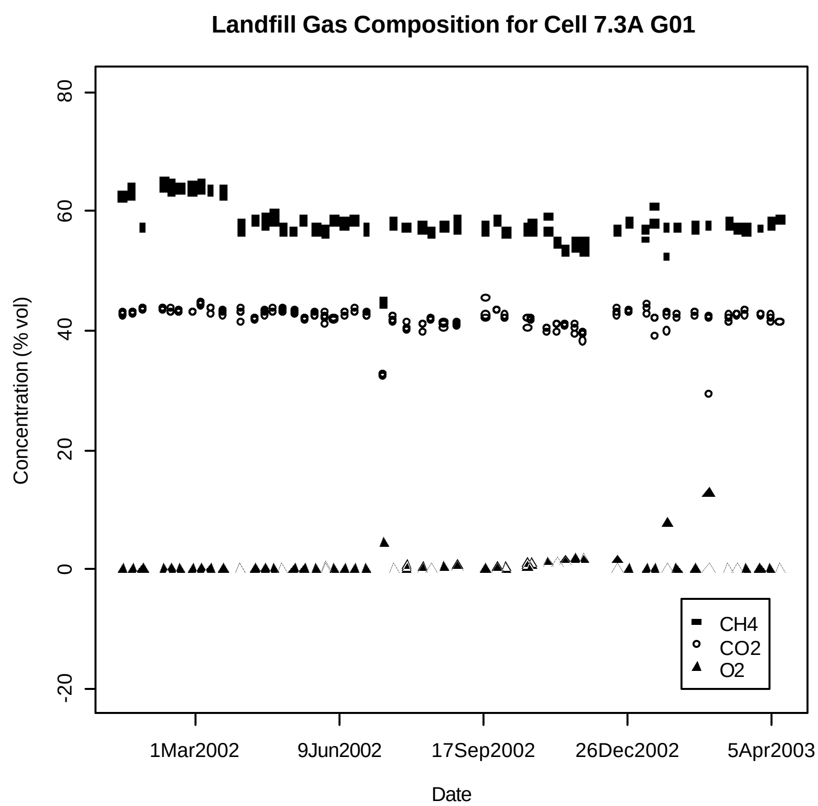
The field gas plots for the control cells and FLB cell 5.1 are very similar in nature. Compositions are the same with all exhibiting a flat linear behavior in time. FLB cell 5.1 shows a slightly higher degree of variability than the control cells.

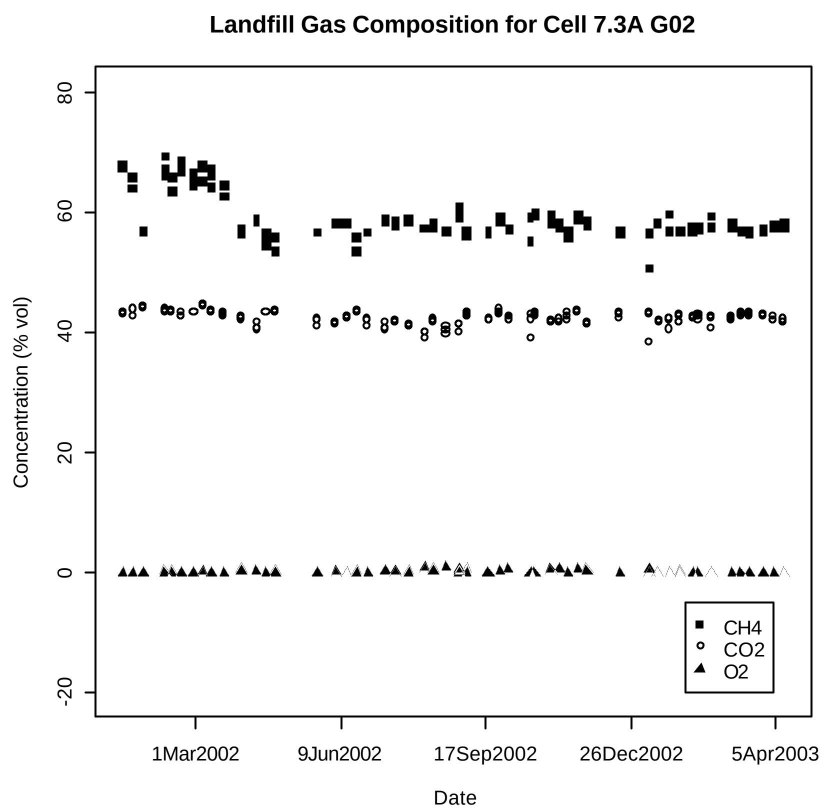
FLB cell 5.2 is quite different than the other cells. At the beginning of observation, gas composition is quite similar to the other cells. Then on approximately March 1, 2002 after a period of flat linear behavior, there is a dip in methane and carbon dioxide (with a corresponding increase in oxygen) concentration levels for a period of approximately 10 months. Finally, on approximately January 1, 2003, field gas levels return to those of the other cells.



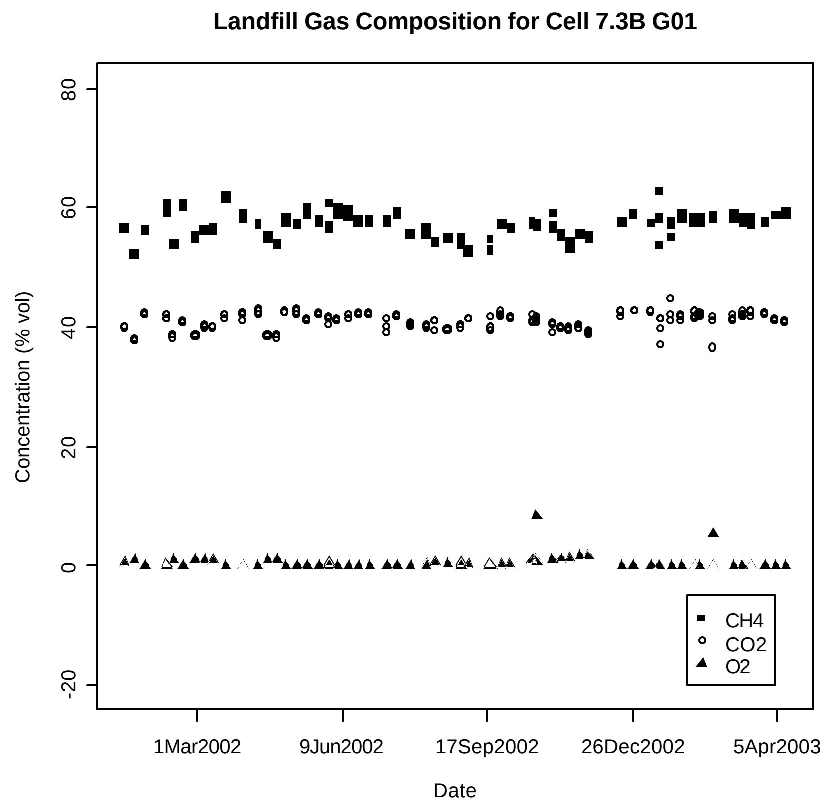


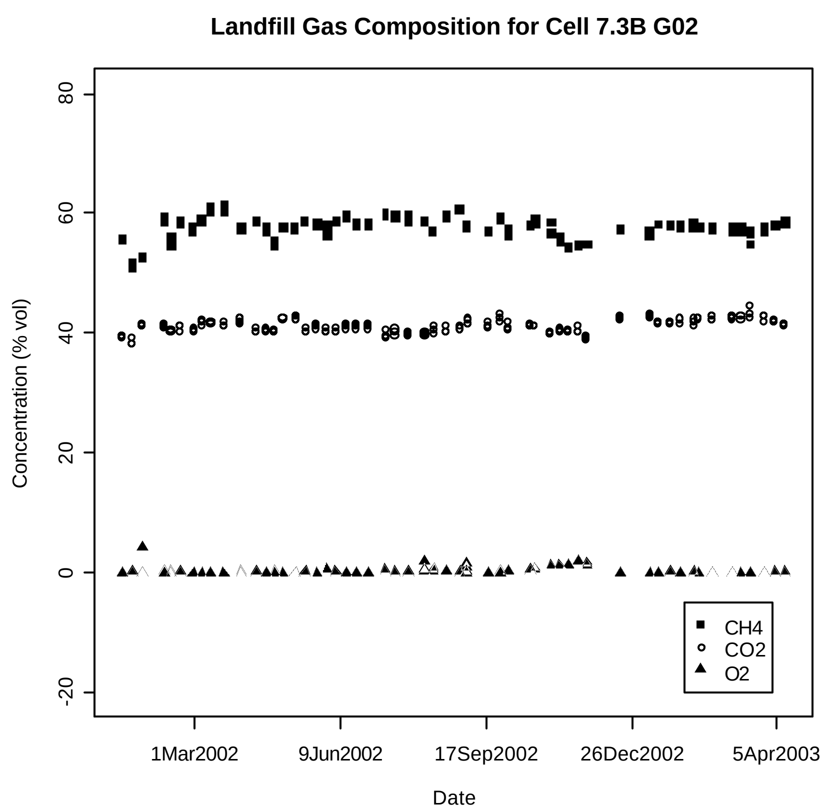
** 5.1=FLB cell 5S*
5.2=FLB cell 5N





** 7.3=AALB cell 7.3*





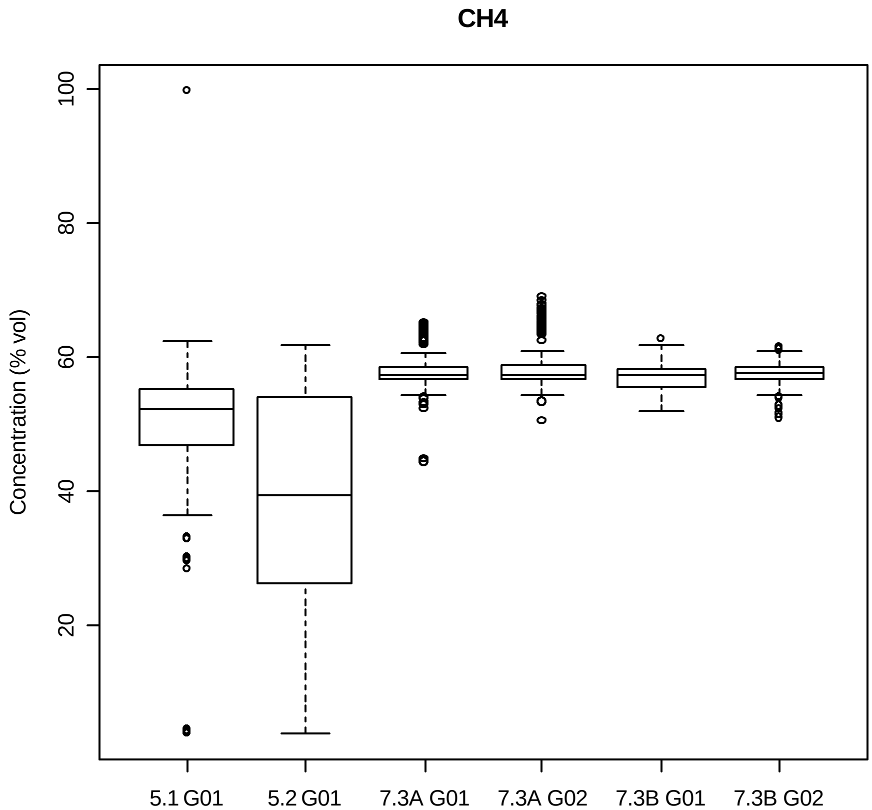
* *7.3=Control cell 7.3*

FIELD GAS BOX-PLOTS

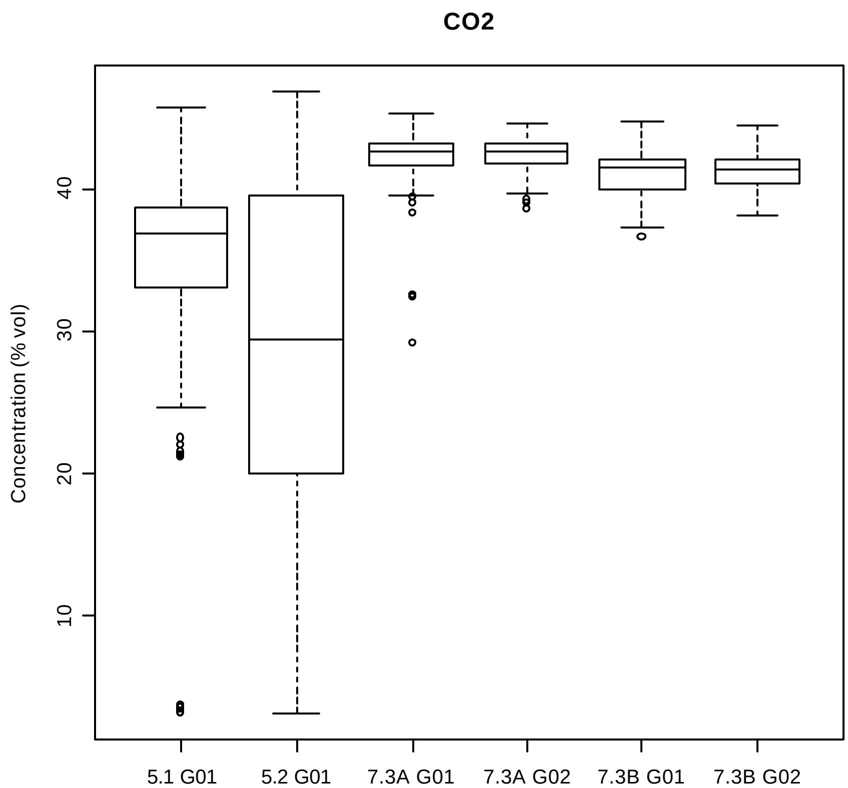
Summary

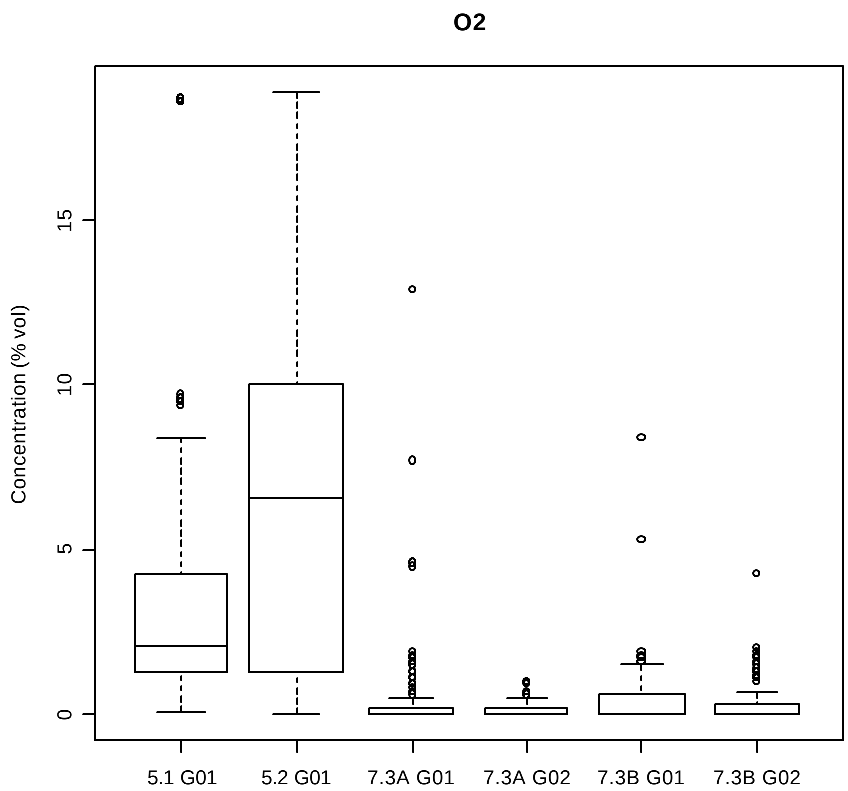
The first tool we use to investigate the dataset are boxplots, or box and whiskers plots. A box and whiskers plot is composed of a central box divided by a line and two lines extending out from the box called whiskers. The length of the central box indicates the spread of the bulk of the data (the central 50%) while the length of the whiskers show how stretched the tails of the distribution are. The width of the box has no particular meaning; the plot can be made quite narrow without affecting its visual impact. The sample median is displayed as a line through the box. Any unusually small/large data points are displayed by a circle on the plot. A box and whiskers plot can be used to assess the symmetry of the data. If the distribution is symmetrical, then the box is divided in two equal halves by the median, the whiskers will be the same length and the number of extreme data points will be distributed equally on either end of the plot. A boxplot is a way to visually analyze a dataset's distribution. The 25th and 75th quantile are the endpoints that encompass the filled box. The whiskers extend out to the largest(smallest) data points that lie more than 1.5 times the interquartile range (IQR, the 75th quantile minus the 25th quantile) on each side of the median, a common non-parametric measure to distinguish possible outliers. Potential outliers are then plotted as circles outside of this range. These plots are very useful in making general decisions regarding the distributional form of the data. For example, assumptions of normality imply symmetrical data and if the data do not appear symmetric according to the boxplots there will most likely be problems with assuming normality.

The box-plots for the three field gases demonstrate that the FLB cells contain slightly smaller concentrations of methane and carbon dioxide overall and slightly higher concentrations of oxygen. Also, the control cells contain far less variability in concentration levels. FLB cell 5.2 has a larger variability because of the 10 month decrease in methane and carbon dioxide levels (10 month increase in oxygen levels).



*5.1(2) : *FLB* Cell 5.1(2)   7.3 : *Control* Cell 7.3





*5.1(2) : *FLB* Cell 5.1(2)   7.3 : *Control* Cell 7.3

TREND TESTS

Summary

The Mann-Kendall results must be considered with caution. Well-constructed data sets will be evenly collected over time and must not exhibit any obvious temporal correlation. Both of the assumptions seem to be violated by the data in areas, particularly temporal correlation. Therefore, the results here are strictly qualitative and hopefully will help the reader reconstruct the statistical nature of the data. The Mann-Kendall test attempts to test for the existence of a trend by comparing the signs of pair-wise differences in the data. The null hypothesis is that there is no trend. In our case, the alternative is that there exists a trend, *either positive or negative.* A low p-value will reject “randomness” in favor of the existence of a trend. Further information can then be extracted by viewing the slope estimates. For n data points, the slope estimate is created by computing the $n(n-1)/2$ different slopes estimates between individual points and then selecting the median as the overall estimate. Details can be found in Hollander & Wolfe, pp 416-420, 1973.

LEACHATE – Mann-Kendall Test

p-values (*values below 0.05 in* ***bold***)

Cell	BOD	COD	Ammonia (As N)	Total Kjeldahl Nitrogen (TKN)	Phosphorous, Total
Control cell 7.3A	0.112	1	0.922	0.108	0.697
Control cell 7.3B	**0.0372**	0.576	**0.0252**	0.0635	0.441
AALB cell 7.4A	**0.035**	**0.029**	0.127	1	**0.0134**
AALB cell 7.4B	**0.0000817**	**0.00114**	0.0529	0.806	0.127
FLB cell 5.1A	0.337	0.607	**0.0399**	**0.00915**	0.627
FLB cell 5.1B	**0.000958**	**0.0122**	0.0907	0.251	**0.00591**
FLB cell 5.2A	**0.000246**	0.381	**0.000147**	0.108	0.0512
FLB cell 5.2B	0.291	0.131	**0.00152**	**0.0476**	0.952

Slope Estimate
(change/day, pos. in red, neg. in blue, significant slopes “grayed”)

Cell	BOD	COD	Ammonia (As N)	Total Kjeldahl Nitrogen (TKN)	Phosphorous, Total

Control cell 7.3A	-0.0628	0.00208	0.0234	-0.641	0.00016
Control cell 7.3B	-0.502	-0.593	0.6	-0.3	0.00256
AALB cell 7.4A	5.79	9.28	0.785	-0.267	0.0123
AALB cell 7.4B	-17.1	-20	1.66	-1.58	0.00803
FLB cell 5.1A	-0.0631	0.167	-1.58	-3.75	0.000789
FLB cell 5.1B	-0.23	-1.67	-1.14	-2.94	0.005
FLB cell 5.2A	-0.411	-1.76	-2.37	-4.7	-0.00683
FLB cell 5.2B	-0.0764	-0.476	-1.03	-3.5	0.000152

FIELD GAS – Mann-Kendall Test

p-values (*values below 0.05 in **bold***)

Cell	CH4	CO2	O2
Control cell 7.3A G01	**1.481e-08**	**2.387e-08**	**0.0137**
Control cell 7.3A G02	**4.613e-06**	**0.0006**	0.4653
Control cell 7.3B G01	0.0559	**0.0100**	**0.0022**
Control cell 7.3B G02	0.1992	**1.179e-08**	0.1485
FLB cell 5.1 G01	0.0853	**0.0385**	**0.0391**
FLB cell 5.2 G01	**0.0037**	**0.0010**	**0.0004**

Slope Estimate
(change/day, pos. in red, neg. in blue, significant slopes "grayed")

Cell	CH4	CO2	O2
Control cell 7.3A G01	-0.006667	-0.003187	0.000000
Control cell 7.3A G02	-0.006452	-0.001832	0.000000
Control cell 7.3B G01	0.002083	0.001875	0.000000

Control cell 7.3B G02	-0.001049	0.003704	0.000000
FLB cell 5.1 G01	-0.005424	-0.004786	0.001550
FLB cell 5.2 G01	-0.021591	-0.014725	0.007919532

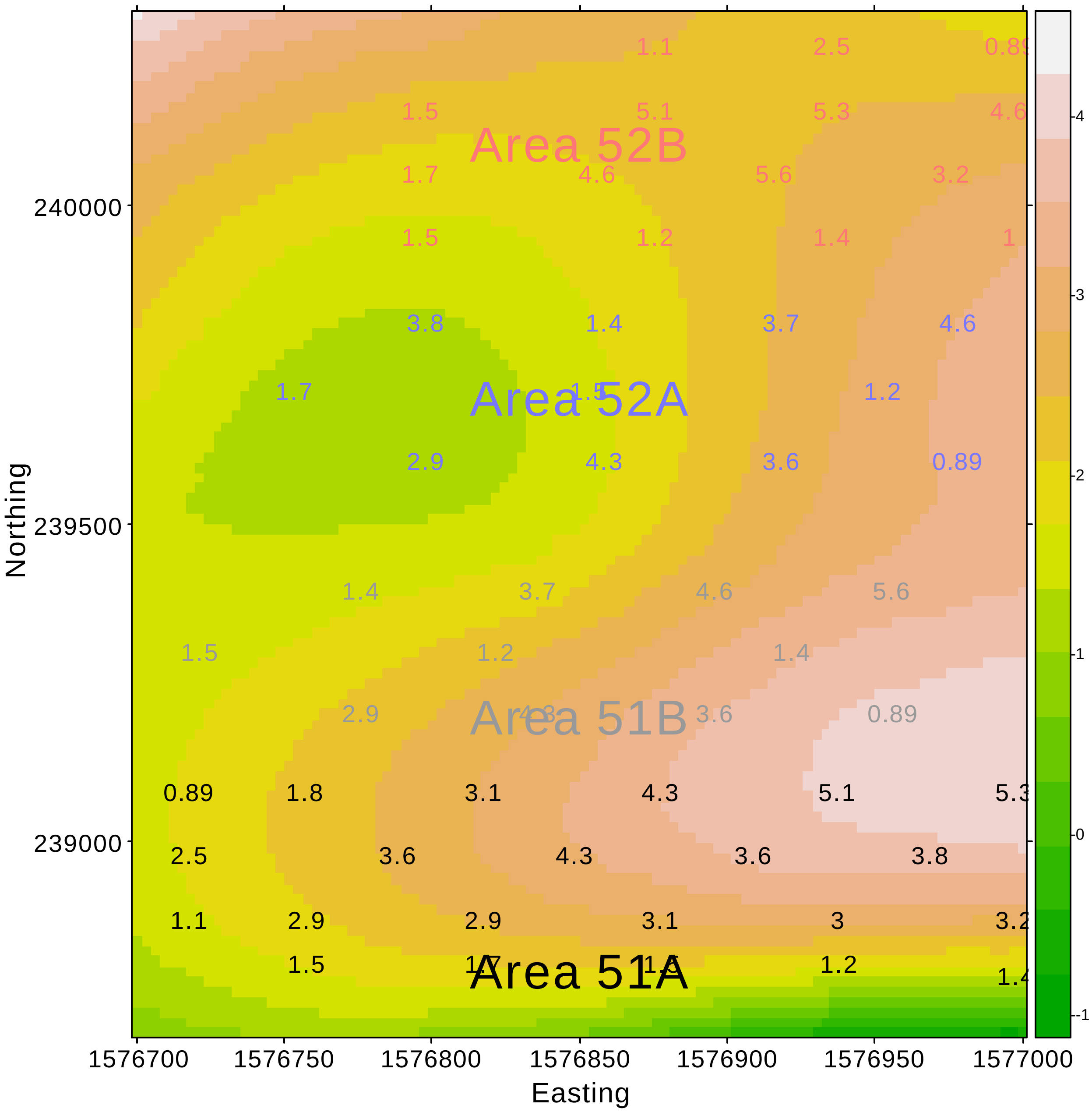
Interpretation

A good example to start with is the AALB 7.4 data, which appears to be trended strongly for both 'replicates' in most parameters that were analyzed. A review of the time plots shows that this indeed seems to be the case and regardless of any violations of the assumptions, there appears to be trends present. This is most likely a function of the relatively young age of the landfill cell. FLB cell 5.1B illustrates some of the hazards of applying a simple trend test to data that shows serial correlation. There does not seem to be an overall positive/negative trend for most parameters but it appears that a trend exists according to the test. This could be caused by the obvious temporal correlation in the data and the fact that this is normally a major violation of the Mann Kendall assumptions. If this correlation continues to be evident with increased data then a time series model will most likely need to be fitted to the data in order to remove the temporal correlation that is being seen. Although it is possible, it is somewhat premature at this point to assume a model structure for the many of these parameters given only a couple of years of data. The heterogeneous nature of the patterns seen (in the time leachate plots) do not yet give rise to a common model that will be needed to make comparisons.

SETTLING DATA

Levelplot of Settling Height in FLB Cell

(7/01/2001 thru 6/1/2003)



NOTE:

The procedure for this analysis is as follows. A local multi-variate regression model is fit to the spatial parameters (Easting and Northing). The local least squares criterion is then minimized to produce estimates of the coefficients, and the resulting plane estimate from which the estimate at the point is created. The proceedure is repeated for each point of estimation. The amount of smoothing that is done to the data is highly dependent upon the value of h chosen. A large bandwidth h leads to a lot of smoothing since many data points are used in the smoothing. A small h leads to a very noisy estimate since only points right in the vicinity of the fitting point are being used for the estimate. In this model, the variable bandwidth h represents a nearest-neighbor based bandwidth that utilizes the closest 50% of the data points *which is a somewhat average bandwidth.*

Care must be taken in interpreting these plots. First and foremost, the map is only really applicable within the confines of the sampling, the area in which the sampling was done. In addition to this, it must be realized that smoothing estimates near the edge of the sampled area may not be as reliable as those near the middle. Confidence bounds on the contours were not attempted here and would probably take a serious effort to creat, assuming we could find a method for which the assumptions were satisfied.

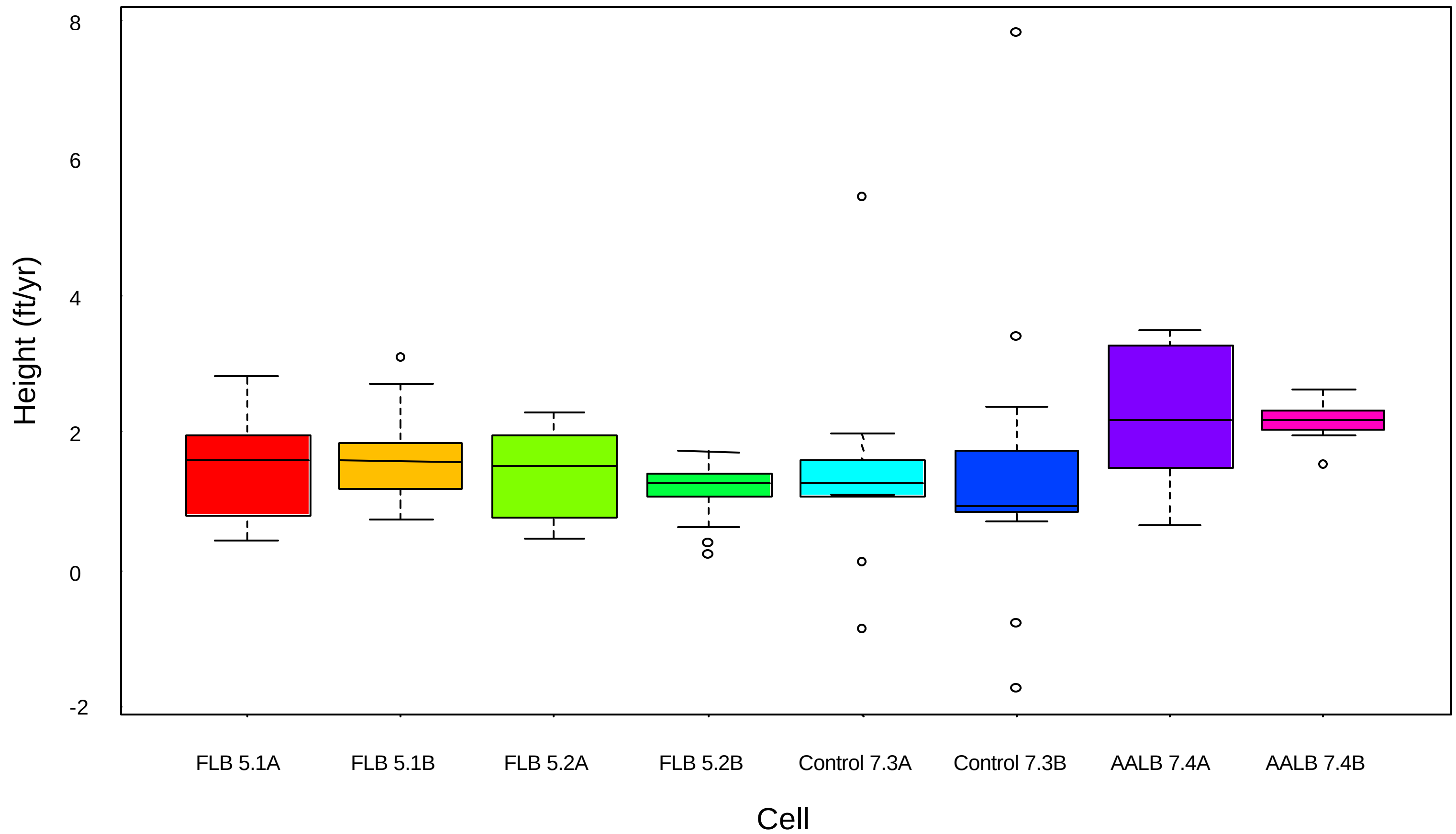
Summary of FLB cell 5.1/FLB cell 5.2 Levelplot

Settling heights do not appear to be strongly correlated although there does appear to be some mild correlation. A few anomalies seem to exist, one in particular in the east section of Area FLB cell 5.1B where there is a 1.4 ft. and a 0.89 ft. result that are amidst much higher results. Bigger differences seem to exist towards the center/east portions of the cells. As more data becomes available, it may be useful to attempt other modeling strategies.

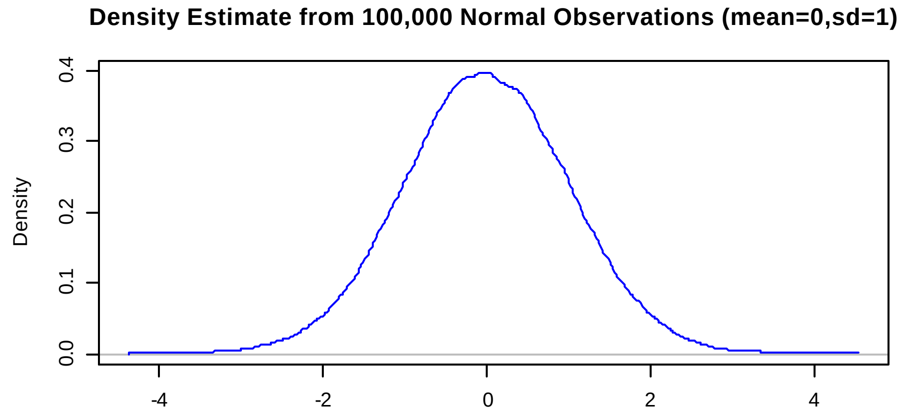
The data available for settling in Control cell 7.3 and AALB cell 7.4 was too sparse and discontinuous to warrant a spatial smoothing plot. We hope that in future the data collected will be less impacted by earth moving equipment and perhaps give us additional insight into the spatial nature of the settling in the control and ALLB cells.

Boxplot of Mean Annual Differences in Height

An explanation of what a *boxplot* is can be found in the previous section on FIELD GAS BOX PLOTS.



A formal definition of *normality* can be found in any introductory statistics book. For our purposes, one can assume we are testing for the special 'bell' shape that defines it (empirical density estimate from Normal distribution shown below).



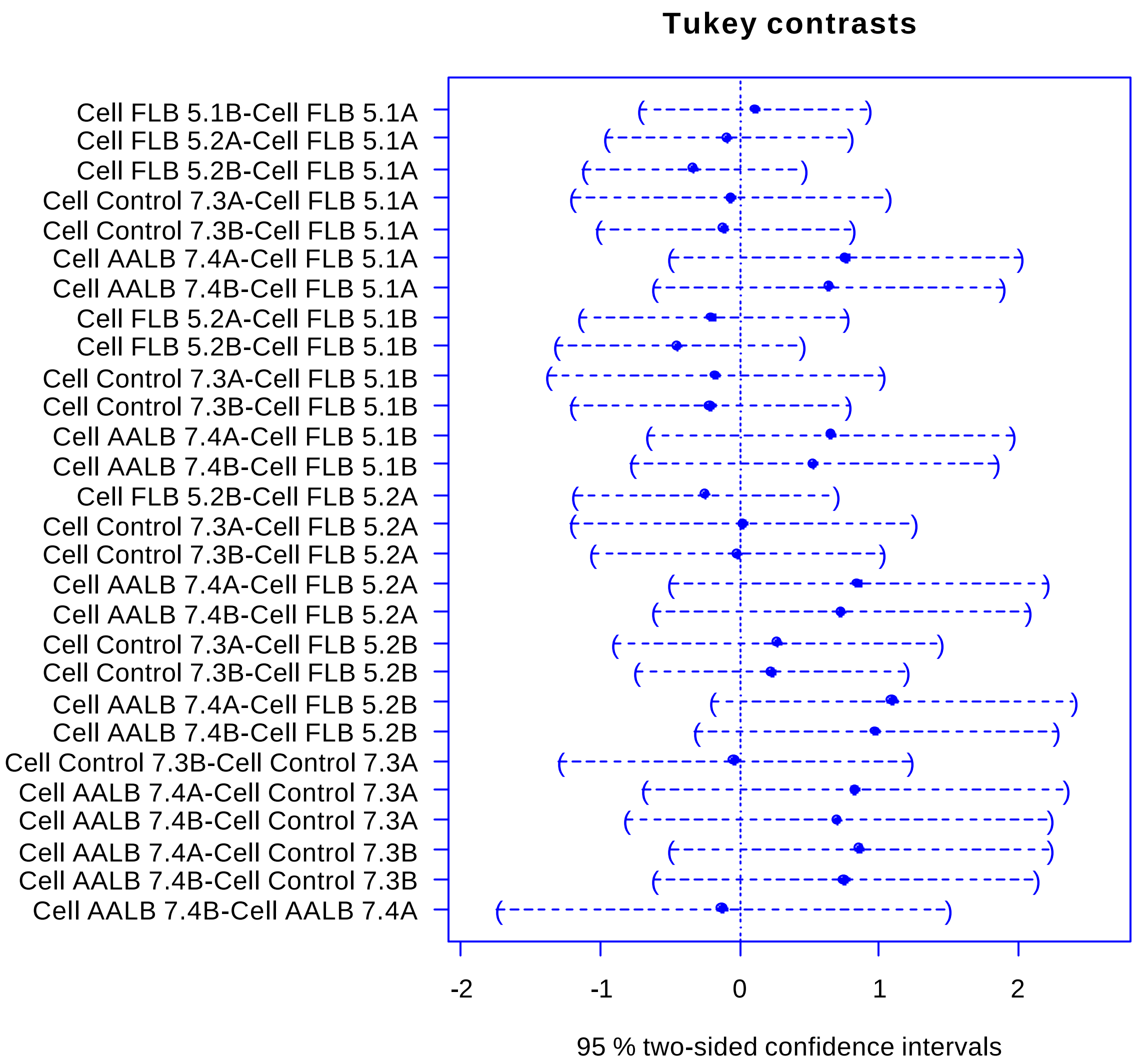
According to the Shapiro Wilk (*Patrick Royston, Algorithm AS 181: The W Test for Normality. Applied Statistics, 31, 176-180, 1982*) normality test results shown below, the data doesn't seem to deviate too far from normality. There are two rejections of normality out of the eight data sets. When reviewing the boxplots of these two cases, one can see that both are *skewed* upward, indicated by the median being less than halfway up the main boxplot body. However, there are two others that would be rejected if the significance level was 0.10 instead of 0.05. Overall, this is not a strong case for normality.

Shapiro Wilk Normality Test

Cell	FLB 51A	FLB 51B	FLB 52A	FLB 52B	Control 73A	Control 73B	AALB 7.4A	AALB 74B
p-value	0.077	0.246	0.145	0.064	*0.049*	*0.001*	0.356	0.872

Given this, we will include two analyses of differences between the eight sets. First, a Tukey multiple comparison test will be performed giving 95% two-sided confidence intervals for each pair-wise difference of means. The multiple comparison procedure accounts for the fact that multiple comparisons are being performed and adjusts the confidence intervals accordingly.

As one can see by reviewing the graph above, every confidence interval contains zero and therefore we can't reliably conclude that there is a difference between any of the settling cell data sets. The cell that appears closest to being distinguished is cell AALB cell 7.4. However, earth activity caused a large portion of the data to be ignored, which lowered the sample size for this cell and could have had some effect upon the analyses. In addition to this, the large number of comparisons required in conjunction with the multiple comparison approach, makes it very difficult for the test to show a significant difference.



Since this procedure depends upon the normality of each individual data set, we will also include some simple non-parametric pair-wise comparisons, which do not necessarily account for the multiple comparisons. In lieu of being a multiple comparison procedure, they should still provide additional evidence for the analysis. In particular, the Wilcoxon Rank Sum Test tests for a difference between the locations of two similarly shaped distributions. The null hypothesis is that the two variables, for instance FLB cell 5.1B and FLB cell 5.1A, have the same *unspecified* probability distribution. The alternative is that one variable tends to be *larger/(smaller)* than the other. A common way to visualize this is that one variable's distribution is the same as the other except shifted to the left (smaller) or right (larger). Therefore, an assumption of the test is that both variables' distributions are similarly shaped, which can't be stated conclusively here and upon further review might even be stated as unlikely. Nevertheless, it provides a bit more support for what we see in the boxplots.

Individual Wilcoxon Rank Sum Tests

Cell Difference	p-value
FLB cell 5.1B-FLB cell 5.1A	0.631
FLB cell 5.2A-FLB cell 5.1A	0.717
FLB cell 5.2B-FLB cell 5.1A	*0.016*
Control cell 7.3A-FLB cell 5.1A	0.323
Control cell 7.3B-FLB cell 5.1A	0.296
AALB cell 7.4A-FLB cell 5.1A	0.131
AALB cell 7.4B-FLB cell 5.1A	*0.014*
FLB cell 5.2A-FLB cell 5.1B	0.527
FLB cell 5.2B-FLB cell 5.1B	*0.006*
Control cell 7.3A-FLB cell 5.1B	0.349
Control cell 7.3B-FLB cell 5.1B	0.057
AALB cell 7.4A-FLB cell 5.1B	0.199
AALB cell 7.4B-FLB cell 5.1B	*0.013*
FLB cell 5.2B-FLB cell 5.2A	0.166
Control cell 7.3A-FLB cell 5.2A	0.554
Control cell 7.3B-FLB cell 5.2A	0.501
AALB cell 7.4A-FLB cell 5.2A	0.125
AALB cell 7.4B-FLB cell 5.2A	*0.012*
Control cell 7.3A-FLB cell 5.2B	0.907
Control cell 7.3B-FLB cell 5.2B	0.291
AALB cell 7.4A-FLB cell 5.2B	*0.007*
AALB cell 7.4B-FLB cell 5.2B	*0.000*
Control cell 7.3B-Control cell 7.3A	0.445
AALB cell 7.4A-Control cell 7.3A	0.138
AALB cell 7.4B-Control cell 7.3A	*0.026*
AALB cell 7.4A-Control cell 7.3B	0.102
AALB cell 7.4B-Control cell 7.3B	*0.021*
AALB cell 7.4B-AALB cell 7.4A	0.949

The Wilcoxon Rank Sum Tests seem to pull out AALB cell 7.4B in particular as one with increased settling differences, relative to the others. However, there is a large difference in running these non-parametric tests individually (*not as a multiple comparison)* and the confidence level of the overall set of comparisons would be much lower than that of the Tukey multiple comparison test. This is far from conclusive evidence, however, qualitatively with all evidence combined, it does appear that AALB cell 7.4B does exhibit larger settling values in general.

OUTER LOOP LANDFILL BIOREACTOR DATA

This document summarizes the data that Neptune has received to date from WMI and/or EPA/NRMRL. The data fall into 4 groups which might be labeled:

1. Leachate (monthly and quarterly data collected from all disposal cells)
2. Solids (weekly data collected from the control and FLB cells)
3. Landfill Gas (quarterly data collected from the control and FLB cells)
4. Field Gas (weekly data collected from the control and FLB cells)

The disposal cells have been labeled somewhat differently in the data files received. We will use the following denotation:

A. 73A and 73B – two control disposal cells
B. 74A and 74B – two AALB treatment disposal cells
C. 51A, 5 S-, 52A, 52B – four FLB treatment disposal cells

1. The leachate data are labeled this way with an "L01" extension.

2. The solids data are labeled this way for the control disposal cells with extensions that identify specific locations (e.g., 7.3A-1). For the FLB treatment cells, the solids data have been labeled 5N-x and 5S-x indicating north and south disposal cells and with x denoting a specific location. The locations also indicate which FLB treatment disposal cell applies: x in the range 1-6 for 5N implies 52B, in the range 21-26 for 5N implies 52A; x in the range 1-6 for 5S implies 51A, in the range 21-26 for 5S implies 5 S-. Locations for the solids data have been provided for the FLB treatment and control cells in terms of (x,y) coordinates in hard copy form and have been entered electronically into the database.

3. The landfill gas data are labeled 73A and 73B for the control cells. For the FLB treatment cells the labels are 51 and 52, implying that landfill gas data were not collected on a more refined level (e.g., 51A and 5 S- separately), with an extension of "G01".

4. The field gas data are labeled 73A and 73B for the control cells. For the FLB treatment cells the labels are 51 and 52, implying that landfill gas data were not collected on a more refined level (e.g., 51A and 5 S- separately), with an extension of "G01" or "G02".

One other attribute of the data that will be relevant for data analysis is the temporal information. Different data were collected at different times and with different periodicity, as follows:

1. The leachate data were provided in 27 data files that cover the following dates, with the corresponding number of data rows in each file:

6/1/01 – (615)	6/25/01 – (801)	6/26/01 – (615)
7/11/01 – (1042)	7/12/01 – (188)	11/15/01 – (1217)
12/17/01 – (36)	12/18/01 – (86)	1/10/02 – (120)
2/11/02 – (120)	3/19/02 – (752)	3/20/02 – (1067)
4/11/02 – (106)	4/12/02 – (24)	5/13/02 – (63)
5/14/02 – (61)	6/10/02 – (1603)	7/16/02 – (120)
8/7/02 – (128)	9/16/02 – (1553)	10/21/02 – (128)
11/14/02 – (128)	12/16/02 – (1408)	1/22/03 – (113)
2/12/2003 – (121)	3/18/03 – (1552)	4/10/03 – (120)

The number of data points in each data set depends on the number of parameters measured. The leachate data are recorded monthly for some parameters and quarterly for many more. Hence, when the number of data rows is around 1,000, the data include quarterly results (7/11/01, 11/15/01, 3/20/02, 6/10/02, 9/16/02, 12/16/02, and 3/18/03). The data from June 2001 represent the first rounds of data collected. It appears as though the data collection regime has stabilized since that time, and that more recent data have been collected on a more regular schedule.

2. The solids data are available for 4 days a week in each full week of the month of June 2000. In general, only one or two of those days were used to sample solids from a given location in a given disposal cell (for example, 18 samples were taken from location 73A-1 on 6/6/00, 6 samples were taken from 5N21 on 6/22/00). Samples were taken at each 3 inch depth interval, presumably to the bottom of the samples location bore hole. In total, 171 data points are available from 25 locations from the FLB treatment and control disposal cells.

3. The landfill gas data have been collected quarterly in the following months or dates (with number of data rows in parentheses):

   12/19/01 – (178)   3/21/02 – (453)   6/13/02- 6/28/02 – (466)

   Only a few samples have been collected in each case (e.g., 2 samples on 12/19/02, 6 samples on 3/21/02, and 6 samples on June 2002).

4. The field gas data have been collected approximately weekly since 11/16/01 for the FLB treatment disposal cell, and from 1/10/02 for the control disposal cell. For the control cells approximately 6 samples are included weekly for each cell (73A and 73B). There are a total of 687 data rows for this cell. For the FLB treatment disposal cells approximately 3 samples are included weekly for cell 51 and again for cell 52. There are a total of 207 and 208 data rows for cell 51 and for cell 52, respectively.